machine code sprites and graphics
for the zx spectrum

a complete guide to sprite coding

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First published 1984 by:
Sunshine Books (an imprint of Scot Press Ltd.)
12–13 Little Newport Street
London WC2R 3LD

British Library Cataloguing in Publication Data
Durst, John
Machine code sprites and graphics for the ZX Spectrum.
1. Computer graphics 2. Sinclair ZX
Spectrum (Computer)
I. Title
001.64'43 T385

ISBN 0–946408–51–3

Cover design by Grad Graphic Design Ltd.
Illustration by Richard Dunn.
Typeset and printed in England by Unwin Brothers Ltd, Woking.

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Introduction

This is a book about the Spectrum display. It explains how to print patterns, pictures and letters in a range far more colourful and intricate than you would ever be able to achieve through normal BASIC programming. And you only need the standard Spectrum devices.

You will discover how to draw your own sprites, how to animate them and how to move them about the screen — quite independently of the background. You will learn how to make letters outside the normal Spectrum character range — large letters (from two to eight times normal size), small letters (fitting 40 or even 64 characters to the line) and sideways letters. All of these can be used in your own programs to make them more interesting — more fun.

To do all this, you have to get down to the nitty-gritty of how the character set, the display file and the attributes file are organised. By the end of the book — I hope! — you will be able to manipulate these as neatly and spectacularly as a circus juggler manages his plates and bottles. And once you understand all they do, and everything you can do with them, you will be able to use your Spectrum in ways Sinclair Research never dreamed of!

The techniques described here use machine code most of the time, to get around the restrictions of BASIC. Although I have assumed that you will know something of machine code programming, I have tried to make the *thinking* behind the routines as simple and as logically developed as possible: I hope that everyone will be able to follow the development of each program, step by step.

Nearly all of the routines will stand alone: that is, they can be programmed and run individually to produce a certain result. But few of them are meant to be left at that. They are intended to be used by you — to be adapted and incorporated in your programs, to give you new ideas for better programs. The routines will do what *you* want them to do.

I hope that this book turns out to be useful but, above all, I hope that you enjoy it.

ZX Machine Code User's Club

To keep up to date with machine code techniques, most people reading this book would enjoy the ZX Machine Code User's Club. The club holds meetings, from time to time, and publishes a magazine, 'MicroArts' (with pages numbered in hex!) full of good things. The club is non-profit-making — actually, more loss-making, at the moment. Particulars from the Secretary, Miss Toni Baker, 37 Stratford Road, Wolverton, Milton Keynes MK12 5LW.

Program Notes

Please be careful when entering programs that you key in the correct characters. In particular, the number 1 and lower case l, and commas and full stops, can look very similar.

Page references to the Spectrum manual are to the second edition (1983).

CHAPTER 1
Into Machine Code

Any writer has to start by making some assumptions, and my main one is that the reader of this book will not be a complete novice at machine code programming. You don't think that the 'BC register' is a list of 2000-year-old families, or that 'shift right logical' has something to do with politics.

There are many good introductory books on machine coding, which will take you through the rules of the system and explain how to achieve interesting results. If you are hooked (and you probably must be hooked, to buy this book) you will already have a couple of these works, which explain Z80 coding in terms of the Sinclair Spectrum. But, in addition, I would say that there are at least two 'musts' (or near-musts) which you will never regret having on your shelves.

The first is *The Complete Spectrum ROM Disassembly* (Melbourne House) by Dr Ian Logan and Dr Frank O'Hara. The Spectrum ROM is a treasure-house of routines which can be picked out for use in your own programs (some will be mentioned in the course of this book). The great beauty of them is that, since they are there, already debugged, you don't really have to understand how they work — you just need to know their start addresses and what they will do. But quite often you *might* want to change the rules, perhaps by entering a routine at a later point than normal. To follow what happens in any of these routines, there is nothing like being able to go back to basics and consulting the original listing, which is what you can do with the *Spectrum ROM Disassembly*.

The other book I could not get along without is Rodnay Zaks' *Programming the Z80* (Sybex). It's a big book, I'm afraid, and an expensive one, but it contains *everything* concerned with the Spectrum's microprocessor: if you want to find out what happens to the parity flag after some obscure operation (or, indeed, what the parity flag *is*), then Zaks is your man.

I have done my best in this book to explain the more difficult points, but machine code is an intricate subject and you will no doubt find that other, more detailed, explanations will sometimes make things clearer.

Most of the routines given here have starting addresses at F000h — or sometimes at F100h, or F200h. These are quite arbitrary: in fact, if, as I suggest, the routines form part of a bigger program, you would want to put them at different addresses to form a block with the rest of your program.

The programs were worked out on the 48K Spectrum. However, nearly all of them, except those using very large blocks of memory, will work equally well on the 16K model but, to avoid cluttering already crowded pages, I have not listed the alternative addresses.

If you *are* using a 16K Spectrum, as a general rule, where the 48K Spectrum has addresses beginning at F000h at the very top of its memory, the 16K Spectrum should have addresses beginning at 7000h. So, to fit the routines into a 16K context, you could substitute '7' wherever you find 'F' at the beginning of a hex address (but you would need to check through the programs carefully, to make sure that you had not set any traps for yourself, by doing so.

Hexadecimal v. decimal

The previous paragraph introduces another subject, which we shall need to tackle — the great 'hex v. decimal' controversy. I have used hex addresses because it seems a sensible rule to follow in machine coding, although, when programming in BASIC, decimal notation is really the only option available on the Spectrum. (The limited binary input is chiefly used for creating graphics.)

Why not be consistent and use decimal throughout? The reason is that, in machine code, decimal gives a very poor impression of the underlying binary, which is all the processor understands.

For example, the decimal numbers 19, 27, 35 and 43 are all Z80 instructions. On the face of it, they don't bear much of a family resemblance, although they stand for 'increment DE', 'decrement DE', 'increment HL' and 'decrement HL'. But expressed as hex numbers they become 13, 1B, 23, 2B. You can quickly see that references to the HL register seem to start with '2', while those to the DE register start with '1'; increments of double registers end with '3' and decrements end with 'B'. You could even carry your Sherlocking further and deduce that, if the instruction 'Load BC...' is '01...', then 'increment BC' should be '03'. And you would be right.

However, the Z80 is not entirely based on this idea of 'matching', and other factors intervene. But hex notation brings out the fact that the Z80 instructions are not just a set of arbitrary codes — they are a logically constructed family in which the binary on/off signals carry out a planned structure of tasks.

All this makes it worth our while to use hex notation in setting out machine code routines. I confess that I have never succeeded in learning my 'hex times tables' properly: I always look them up, even if I think I know them. The single-byte codes are easily found from the character set in the Sinclair manual, on pp.183–188, and most machine code primers have tables from which to work out the longer numbers. If you feel that this involves too much effort, or takes too long, the complete program discussed in Chapter 13 is a machine code routine to convert hex into decimal, and vice versa, which works almost instantaneously.

I should point out here that all references to the Spectrum manual will be to the second edition of the manual, which was produced in 1983.

Hex Entry

Understanding the principles of machine coding is not the same thing as using it: you need more than this if you are going to construct practical programs. Apart from notebook, pen, pocket calculator and reference books, you need some method of entering the machine code on the Spectrum.

All introductory books on machine coding list some method of setting up code in the RAM. They vary in complexity, but all do an efficient job of transforming your jabs at the keyboard into bytes stored in the Spectrum memory. However, I've included another system here.

```
   1 REM **POKE HEX $STRING**
   2 INPUT "Start address? ";ad
   3 LET ad1=INT (ad/256): LET ad2=ad-25
6*ad1
   4 POKE USR "A",ad2: POKE USR "A"+1,ad
1: CLEAR ad-1
  10 DEF FN a(j)=CODE a$(j)-48-7*(CODE a
$(j)>=65)
  20 DEF FN b$(x)=CHR$ (INT (x/16)+48+7*
(INT (x/16)>9))
  30 DEF FN c$(x)=CHR$ (x-16*INT (x/16)+
48+7*((x-16*INT (x/16))>9))
  40 LET a$="21FF00C9"
  50 IF LEN a$<>2*INT (LEN a$/2) THEN PR
INT "Hex digit missing": STOP
  60 FOR j=1 TO LEN a$: IF NOT ((a$(j)>=
"0" AND a$(j)<="9") OR (a$(j)>="A" AND a
$(j)<="F")) THEN PRINT "Fault at ";j;" =
 ";a$(j): STOP
  70 NEXT j
  80 LET ad=256*PEEK (USR "A"+1)+PEEK US
R "A"
  90 FOR j=1 TO LEN a$ STEP 2: POKE ad-1
+j/2,16*FN a(j)+FN a(j+1): NEXT j
  95 PRINT "Code entered": STOP
```

```
 100 REM ***PRINT HEX PAIRS***
 110 INPUT "Start address? ";ad
 120 FOR j=ad TO ad+100
 130 LET ad1=INT (j/256): LET ad2=j-256*
ad1
 140 LET byt=PEEK j
 150 PRINT j;TAB 10;FN b$(ad1);FN c$(ad1
);FN b$(ad2);FN c$(ad2);TAB 18;FN b$(byt
);FN c$(byt)
 160 NEXT j
```

This program asks you to set up a string in line 40(a$) which contains the standard hex listing for your routine (using the digits 0 to 9, and the letters A to F). Lines 50–70 check that the string holds valid notation, after which line 110 asks for a start address in decimal. When that is entered, the program POKEs the required values to the chosen addresses.

The second part of the program, from line 100, allows you to display the hex values of a series of bytes, starting from a chosen address. It also displays the address of each byte in decimal and hex.

While this is not a proper disassembly, it allows a quick check of an entered program—or of any other region of the memory. It can, of course, be made to LPRINT, if required.

The main advantage of this particular Hex Entry program lies in the fact that the listing is always preserved in 'a$'. This makes it possible to edit the coding — to change it, debug it, etc. (Most hex loaders involve typing in code which is immediately POKEd into memory, leaving you with nothing you can see.)

Also, the first thing you learn about machine coding is that the tiniest error seems to end in total disaster, general paralysis of the computer, etc., etc. If you are wise, you *always* SAVE your program, before running it. By having the routine in a string, it can be SAVEd along with the BASIC program, without having to do an extra SAVE and then LOAD bytes, as is the case with programs which load the code straight into the memory.

Storing machine code

It's a nice point to decide whereabouts in the RAM to store machine code. The upper RAM is the location favoured by Sinclair Research (see the manual, p.168) and the 'CLEAR xxxxxx' command has been included in the Spectrum layout partly to provide safe space in which to hold the code while a program is being RUN.

As I've said, most of the routines in the present book have been placed at, or about, F000h — sometimes E000h — and, although the decimal equivalents are not very memorable, '61440' and '57344' soon get etched on to your brain. To provide safe areas for these two starting points, you have to CLEAR one digit less — that is, 'CLEAR 61399' and 'CLEAR 57343'.

Another useful location for the machine code is in a REM statement in line 1 of a BASIC program. A BASIC program on the Spectrum does not have a fixed location, but, in practice, the unexpanded Spectrum always has the first character of a line 1 REM statement at 23762. However, if you have an Interface 1 connected, beware! You will have to find the address you need indirectly, using the system variable, PROG, as outlined in Chapter 6.

The REM statement provides a useful place for a shortish routine, closely linked to a BASIC program, as in the case of the Titivator program in Chapter 6, which uses a machine code routine to produce oversize letters. A program at this location loads automatically and is out of the way of any other pieces of machine code which you may have in action (as might be the case when using Titivator).

The technique used is to prepare a REM line with the required number of 'spaces' and then POKE the code bytes into it (**Figure 1.1**).

```
   1 REM 11111111111111111111111
11111111122222222222222222222222
22222222233333333333333333333333
33333333344444444444444444444444
```

Figure 1.1: Line 1 REM Statement

It's handy to use numbers for the spaces, because then you can calculate the total easily, since each line contains 32 'spaces'.

Quite often, the fully POKEd REM won't LIST properly, but this doesn't make any difference to the way in which the program works.

If you use the BASIC Hex Entry program to prepare your line 1 REM, you can scrap the entry program once the REM is ready and then MERGE the line 1 with your final BASIC application program for subsequent use.

Assemblers and disassemblers

The trouble with simple hex loaders is that they don't provide any method of viewing the machine code program, other than as a raw hex listing. The best you can hope for is

3A 08 5C D6 20 18 06

rather than

```
F000    3A 08 5C    LD A,(5C08)
F003    D6 20       SUB 20
F005    18 06       JR, F00C
```

let alone

```
F000    3A 08 5C    LD,A (LAST_K)
F003    D6 20       SUB 20           ;GET KEY VALUE
F005    18 06       JR, PRINT
```

Obviously, the more detailed the final printout becomes, the more complicated the program to produce it must be. To get a proper mnemonic display, you really need to buy a professionally-prepared program, on cassette.

These cassette-based programs come in two basic kinds, the 'assemblers' and the 'disassemblers', and, as usual, there is a trade-off between the two when it comes to using them. The assemblers let you key in the Z80 mnemonics direct, from which they will put together the machine code listing — the 'object code'. With a disassembler, you usually have to key in the object code, but you have excellent facilities for display and editing.

The disadvantage of an assembler lie mostly in the fact that it has to be a very complicated program and may not be very user-friendly. It can be as fiddly to key in the source code and to get all the commas, spaces, labels, etc., right, as it is to look up the object code and enter that in a disassembler. You often have to spend quite a long time debugging the source code in the assembler, before you can check whether the program itself will run! On the other hand, assemblers will usually cope with labels, calculate relative jumps and do many similar chores. But a good disassembler will let you debug much more thoroughly, providing BREAK points, facilities for juggling blocks of code, and so on.

There are some super-programs, which combine the virtues of both, but they nearly always need an 80-column printer, and so are more for the software professional than for us poor mortals.

My personal preference is for the disassembler type of program — I like to feel close to the object code. But I freely admit that this is a personal bias, and the Z80 will probably be one of the last microprocessors on which it will be practical. The next generation of 16-bit processors, like the 68008 in the Sinclair QL, will be just about impossible to handle, except through an assembler.

CHAPTER 2
The Memory

A computer works by moving electrical charges about within the microprocessor chip and the memory chips. There are two sorts of memory 'ROM', or read only memory, and 'RAM', or random access memory: (called 'random access memory' because you can access any memory location you wish within it).

Conventionally, as a working analogy, each is pictured as a long line of numbered boxes, each containing an 8-bit byte.

In the Spectrum, the line begins at 0000h and ends at FFFFh (or 7FFFh, if we are dealing with the 16K Spectrum). Notice, by the way, how computers like to begin their counting at '0', rather than at '1' like us mortals. It is, in fact, more logical and it is not a bad habit to adopt when writing programs: then there should be no confusion.

When dealing with machine code, it is essential to be able to find your way about the various sections of the ROM and RAM and a map, or plan, of the layout comes in very handy.

The memory map in **Figure 2.1** is not complete. Other versions will be found in the Sinclair manual and in most machine code books on the Spectrum. The present version has been tailored to suit our particular needs and it does leave out details which are not relevant here.

Much of it will probably be familiar, but it may still be a help to take a quick canter down 'memory lane'.

The memory map

Starting at the bottom, the section of memory from 0000h to 3FFFh is the ROM. This is the powerhouse of the Spectrum and is unchangeable, although its contents can be studied. It is used in most programs, both BASIC (in which it is invariably used) and machine code, when it can be used if it is helpful. Whole books are written about the ROM and we shall look at some parts of it later on.

Beyond the ROM, memory is more unstable. It can be filled with information by the computer operator, or from a cassette or Microdrive, but it always reverts to a blank when the power is switched off — as many of us know only too well.

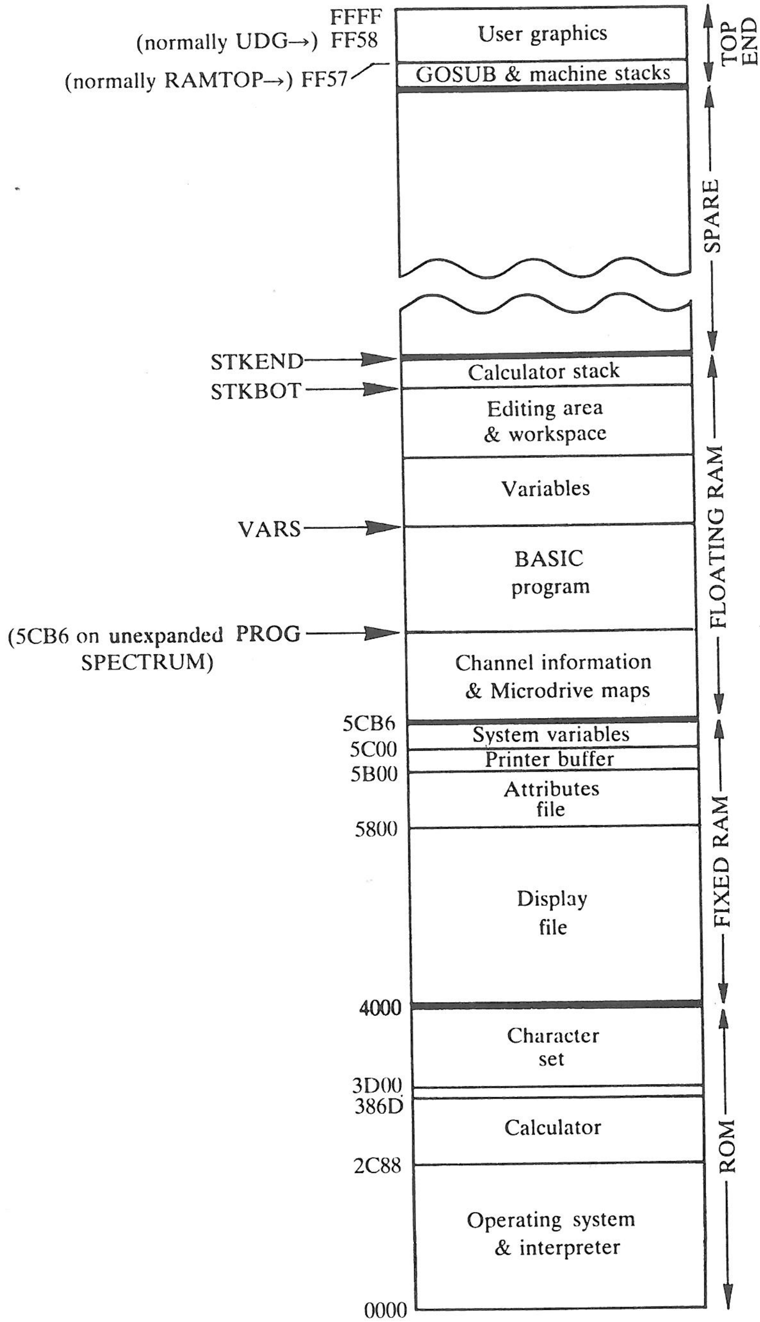


Figure 2.1: Spectrum Memory Map

The first section immediately above the ROM, is called the 'fixed RAM'. This contains divisions exploited by the ROM, at fixed addresses: a whopping great chunk to hold the display file and colour attributes for the television; a small section where material is assembled for the printer; and the very important section which holds all the addresses used by the ROM (or by us) when operating the Spectrum — the system variables.

Beyond this point, the RAM becomes even more vague, the 'floating RAM'. The sections have no predetermined length, though their addresses are always computed in the ROM and then held in the system variables.

There are sections dealing with channel information and the Microdrive. Beyond them comes any BASIC program we have written, with the variables used in that program. Finally come the locations which the Spectrum uses for dealing with a BASIC program — the workspace, editing area and calculator stack.

Beyond all this is spare space. It may be large or small, depending on how much there is in the BASIC program and its variables. Whatever spare space there is can be filled with other data or machine code. This is the area of RAM which we shall be using most frequently in order to write and execute our machine code routines.

Rounding off the RAM comes the section I have called the 'top end'. This is usually approached from the top downwards. First there is a part designed to hold user-designed graphics. It is normally the address pointed to by the system variable UDG, but you can always change UDG and make it point somewhere else (which can be very useful). Below the UDG comes an address called 'RAMTOP', with some more 'stacks' (storage spaces for numbers) below it. Any RUN, CLEAR, or NEW operation will normally clear the RAM only as far as RAMTOP (only a complete power-off will clear beyond this point) so, by moving RAMTOP down, you can reserve a patch of memory which is safe from being overwritten by a BASIC operation (see Sinclair manual p.168).

The ROM

The most interesting section of memory is undoubtedly the ROM. Everything the Spectrum does when writing or executing a BASIC program is done through the ROM. It has a program for everything — even if it is just 'Sorry, can't cope...'. In a very real sense, the ROM *is* the Spectrum.

All of these programs are written in Z80 machine code and within the main programs there are scores of self-contained subroutines, which get used as needed to carry out specific tasks. These are the goodies we are after, because they can do these same tasks for us and save us a great deal of trouble. We can poach them, like apples from an orchard!

The ones which will be of interest in the programs to be developed in this book are listed in Appendix B, but there are many more. Now you should be able to see the advantage of having to hand a good, annotated disassembly of the Spectrum ROM, making it possible to locate the section you are interested in and work through the listing to see if it can be used as a subroutine in your own programs. Much of the listing is pretty heavy-going, but you can struggle along, trying out bits here and there. At the very least, it is more fun than the average adventure game.

To illustrate how ROM routines can be used in ways which are not exactly those originally intended, here is a short program which performs an automatic SAVE of bytes. This can be very useful if you have a BASIC program which always goes hand-in-hand with a block of data. The data could be a SCREEN$ or a machine code routine — anything, as long as it is SAVEd as bytes.

This program compiles a label from material within the BASIC program — ie this program can calculate a new label, like a date or an index number, every time it is SAVEd (which can be useful too).

Saver

```
   5 DIM w$(10)
   6 DEF FN a$(x)=CHR$ INT (x/256)
   7 DEF FN b$(x)=CHR$ (x-256*CODE FN a$
(x))
  10 INPUT "Label:";w$: PRINT AT 8,0;"He
ader Label: ";w$
  20 INPUT "Start Address:";st
  30 INPUT "Finish Address:";fi
  40 LET le=fi-st
  50 PRINT AT 10,0;"SAVE bytes from ";st
;" to ";fi
  60 LET z$=CHR$ 3+w$+FN b$(le)+FN a$(le
)+FN b$(st)+FN a$(st)+CHR$ 0+CHR$ 0+CHR$
 33+CHR$ 82+CHR$ 0+CHR$ 229+CHR$ 33+FN b
$(st)+FN a$(st)+CHR$ 229+CHR$ 221+CHR$ 3
3+CHR$ 0+CHR$ 91+CHR$ 195+CHR$ 132+CHR$
9
  70 FOR j=1 TO LEN z$: POKE 23295+j,COD
E z$(j): NEXT j
  80 RANDOMIZE USR 23313
```

Because this is a demonstration program, it shows 'W$' (label), 'st' (start address) and 'fi' (finish address) as INPUTs, but you would normally expect these to be provided, or calculated, within your main program.

Everyone must have noticed, when LOADing a program to the Spectrum, that there is a kind of 'mini-program' which gets LOADed ahead of the main program. This mini-program is known as the 'header' and, as well as the program label, which it prints out, the header contains important information about the main program, which enables the Spectrum to LOAD this properly.

So, before we can look at how the Saver program functions, we need to be clear as to how the header is put together. It consists of 17 bytes, arranged like this:

0	1 2 3 4 5 6 7 8 9 10	11 12	13 14	15 16
	3 LABEL	le	st 0	0

Byte 0 codes for the type of data being SAVEd: '0' for a BASIC program, '1' and '2' for arrays (numerical or character), '3' for a block of bytes. The next 10 bytes hold the program label, normally entered by hand, but here to be found in 'w$'. The header ends with three pairs of bytes, the first pair holding the length of the block to be saved (our variable, 'le') the next the start address of the block (our variable, 'st') and a final pair which, in the case of a code block, as above, are both zero.

All this material is assembled in the first part of z$, in line 60, which is POKEd into the start of the printer buffer at 5B00h by line 70. The printer buffer has been chosen because it is not in use at this point, and its use avoids having to pollute another piece of RAM which might be required for something else.

The second part of line 60, POKEd into the addresses from 5B11h (23313d) onwards, consists of some machine code instructions. Here is what they look like when they have been put into the printer buffer:

Saver Code

```
5B11 21 52 00      LD   HL,0052
5B11 E5            PUSH HL
5B15 21 00 F0      LD   HL,F000
5B18 E5            PUSH HL
5B19 DD 21 00 5B   LD   IX,5B00
5B1D C3 84 09      JP   0984
```

As you can see, they consist of three addresses, two of them PUSHed on to the stack and one loaded into IX, followed by a jump to a ROM routine. To find out what they are doing, we need to look at the ROM SAVE routine.

Start of SA-CONTRL Routine

```
0970 E5           PUSH HL
0971 3E FD        LD   A,FD
0973 CD 01 16     CALL 1601        OPEN LOWER SCREEN
0976 AF           XOR  A
0977 11 A1 09     LD   DE,09A1
097A CD 0A 0C     CALL 0C0A        PRINT LABEL: "start tape..." etc.
097D FD CB 02 EE  SET  5,(IX+02)
0981 CD D4 15     CALL 15D4        WAIT FOR KEY

0984 DD E5        PUSH IX
0986 11 11 00     LD   DE,0011     DE CONTAINS LENGTH OF
                                     HEADER (= 17d)
0989 AF           XOR  A
098A CD C2 04     CALL 04C2        MAIN SAVE ROUTINE
                                     (FOR HEADER)
098D DD E1        POP  IX
098F 06 32        LD   B,32
0991 76           HALT             PAUSE 1 SEC.
0992 10 FD        DJNZ 0991
0994 DD 5E 0B     LD   E,(IX+0B) }
0997 DD 56 0C     LD   D,(IX+0C) } DE CONTAINS "le"
099A 3E FF        LD   A,FF
099C DD E1        POP  IX
099E C3 C2 04     JP   04C2        MAIN SAVE ROUTINE (FOR
                                     BYTES)
```

We don't need to go into details, but the outline of the routine should be clear from the notes. Before the routine starts, HL must hold the start address of the block to be SAVEd and IX must hold the address of the header information. The routine begins by PUSHing HL and then printing out the 'Start tape...' message in lower screen, before waiting for a key to be depressed. Once this happens, the routine stacks IX and loads DE with the fixed header length (17d = 11h). Then it CALLs the main 'SA_BYTES' subroutine at 04C2h. This subroutine will SAVE the number of bytes in the DE register, starting at IX.

Once this has been done, there is a pause. The routine then loads DE with the data block length, using the IX register to pick out the information from the header (IX points to the start of the header). It then POPs to IX the last address from the stack, which was PUSHed from HL, the start address of the block to be SAVEd. IX now holds that start address and the routine is ready to SAVE the block, by jumping to 04C2h again.

Let's look at our three addresses in the printer buffer again. The first one on to the stack will be the last one off and will form the return address for the dangling RET at the end of the second 'SA_BYTES' call. (This, you will remember, was JUMPed into at address 099Eh.) This return address, in fact, just contains another RET — actually, the first to appear in the ROM. This has been borrowed to get us back into BASIC when the whole operation has been completed.

Next on the stack is the start address for the data block (calculated in our BASIC program by FNa(x) and FNb(x). The third is the printer buffer start address, made ready in IX.

If you check 0984h, the ROM address we jump to in the original ROM SAVE routine, you will see that our routine has skipped over all the 'Wait for a key...' information. However, all the necessary addresses are already prepared on the stack and in IX, so that the rest of the ROM routine can go ahead as planned.

To end with, here is the listing as it might appear in a program. You SAVE by 'GOTO 1100' — this will SAVE the program, followed by the CODE bytes. When you come to LOAD, it will LOAD the program and start executing it from line 1000, which immediately LOADs the bytes.

You will have to arrange to CLEAR 'bytes − 1' beforehand.

Saver — example

```
1000 LOAD ""CODE
1010 GO TO 10
1100 SAVE "something" LINE 1000
1110 DIM w$(10)
1120 DEF FN a$(x)=CHR$ INT (x/256)
1130 DEF FN b$(x)=CHR$ (x-256*CODE FN a$
(x))
1140 LET w$="somethingCODE "
1150 LET st=64256: LET le=1280
1160 LET z$=CHR$ 3+w$+FN b$(le)+FN a$(le
)+FN b$(st)+FN a$(st)+CHR$ 0+CHR$ 0+CHR$
 33+CHR$ 62+CHR$ 0+CHR$ 229+CHR$ 33+FN b
$(st)+FN a$(st)+CHR$ 229+CHR$ 221+CHR$ 3
3+CHR$ 0+CHR$ 91+CHR$ 195+CHR$ 132+CHR$
9
1170 FOR j=1 TO LEN z$: POKE 23295+j,COD
E z$(j): NEXT j
1180 RANDOMIZE USR 23313
```

This is just one example of the way in which you can bend the ROM for special purposes. I confess that it takes some courage to tackle anything much more complicated. It can be difficult to trace the programming, even with the help of a printed disassembly of the ROM, and sometimes trial and error can be both error and trial.

CHAPTER 3
Making Bigger Characters

Printing text

The Sinclair Spectrum uses one of the more attractive and readable fonts of computer type. It uses a matrix of 8 × 8 bits to produce the letters, which are stored as eight bytes per letter in the ROM character set at 3D00–3FFFh.

This is quite a lavish use of bits to print characters. Many commercial matrix printers use only 5 × 7, but this means that they have to use some special means to move the print position along, so as to give a space between letters. In addition, the lower case letters cannot have true 'descenders'.

Descenders are the tails of letters such as 'p', 'q' and 'y', which normally hang down below the print line. On a 5 × 7 matrix it is hard to do this, so the manufacturers 'cheat', as in **Figure 3.1**. The result is awkward-looking and makes for poor legibility.

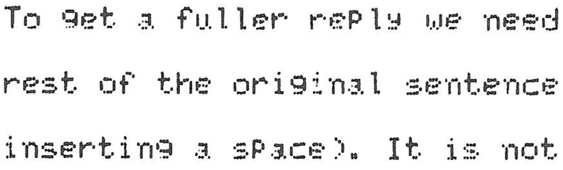


Figure 3.1

On the Spectrum, there are proper descenders and the eight-bit width means that characters can be printed side by side, while still leaving proper spaces between letters. You can see in **Figure 3.2**, where a line has been ruled through the bottom bits of the characters, that the tails of

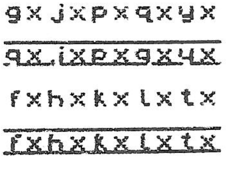


Figure 3.2

q, y, p, q and j actually cut into the bottom line. The 'ascenders' of the letters, t, h, f, k and l just graze the top line.

Before we start seeing how we can play around with the Spectrum character set, perhaps it would be as well to take a quick look at how printing is actually done in the Spectrum.

The key to nearly all Spectrum printing is the 'Restart 10' instruction, in the Z80 codes. This single opcode, 'D7', is used to lead into the main ROM PRINT routine. This routine controls all the Spectrum printing operations, including the setting of colour and other attributes, print position, and so on (see Appendix B).

(The printing of numbers is another matter. This involves placing the value of the number on the calculator stack, in five-byte floating point form, from which it can be picked and printed with decimal point, or in 'exponent' notation. This is done by a ROM routine starting at 2DE3h. However, for our present purposes, the 'RST 10' routine is the one to stick with.)

In order to use this instruction, you first have to choose what kind of printing is to be done. Usually, when dealing with a USR operation, the Spectrum will be in INPUT mode and will print to the bottom of the screen. To get the Spectrum to print to the main screen, you must open channel 'S', by using the instructions 'LD A,02: CALL 1601' (1601h is the address of the 'open channel' routine).

So, to print the letter 'A' on the screen, you need the routine:

Print 'A' ✓

```
F000 3E 02          LD   A,02
F002 CD 01 16       CALL 1601
F005 3E 41          LD   A,41
F005 D7             RST  10
F008 C9             RET
```

If you change the '02' at F001h to '03', the 'A' will be sent to the printer, instead of to the screen. If you change it to '01', the 'A' will go to the INPUT area — but you may not always see it, as the area is usually cleared as soon as the operation is completed. (You can keep the 'A' on the screen by using the BASIC commands 'RANDOMIZE USR 61440: PAUSE 0'.)

To print the 'A' in a specified position, in specified colours, we have to incorporate the appropriate control codes, found on p.183 of the Spectrum manual. To print a green 'A' on a yellow ground, at line 10, column 16d, we could do the following:

Print String ✓

```
F000 3E 02         LD    A,02
F002 CD 01 16      CALL  1601
F005 3E 16         LD    A,16      AT
F007 D7            RST   10
F008 3E 0A         LD    A,0A      10d
F00A D7            RST   10
F00B 3E 10         LD    A,10      16d
F00D D7            RST   10
F00E 3E 10         LD    A,10      INK
F010 D7            RST   10
F011 3E 04         LD    A,04      4
F013 D7            RST   10
F014 3E 11         LD    A,11      PAPER
F016 D7            RST   10
F017 3E 06         LD    A,06      6
F019 D7            RST   10
F01A 3E 41         LD    A,41      CHR$ 'A'
F01C D7            RST   10
F01D C9            RET
```

This is all very well, once in a way, but it's very long-winded and we wouldn't want to use this system to print up a lot of instructions or text in a program.

Fortunately, Sinclair Research have incorporated a string printing subroutine in the ROM, at 203Ch, which gets over most of the difficulties. You need to have the address of the string in DE and its length in BC, before calling 203Ch. The subroutine is essentially a way of looping through the string, using 'RST 10' to print each character in turn.

Our green 'A' now becomes:

Green 'A'

```
F00A 11 00 F0      LD    DE,F000
F00D 01 08 00      LD    BC,0008
F010 CD 3C 20      CALL  203C
F013 C9            RET

DEFB:-
F000 16 0A 10 10 04 11 06 41
```

E000 = 57344
F000 = 61440

The same codes for paper, print position, etc., are still there, but are now grouped together at address F000h. (I have left out the channel selection routine to avoid clutter, but you would still have to incorporate it each time you needed to redirect the printing to the main screen.)

This coding is much more compact, but it can be taken one stage further when there are a lot of messages to be printed in a machine code program.

The first step is to add the length of the string to the front of the data, so that the DEFB (DEFine Bytes) become:

```
DEFB:-
F000 08 16 0A 10 10 04 11 06
F008 41
```

This number can be picked out by the new routine and loaded into BC at the start of the operations.

```
F00A 1A          LD    A,(DE)    FIRST BYTE OF DATA INTO BC
F00B 4F          LD    C,A
F00C 06 00       LD    B,00
F00E 13          INC   DE        POINT TO STRING
F00F CD 3C 20    CALL  203C
```

Once the string has been printed, you can call 203Ch again, this time to print another string, which restores any colour, or other attributes, to their normal condition, so that the current attributes won't hold over into the next bout of printing, which may require something quite different. This is the final section, to carry out the 'housekeeping':

```
F012 01 0C 00    LD    BC,000C   LENGTH OF 'RESTORING' STRING
F015 11 1C F0    LD    DE,F01C   ADDRESS OF 'REST.' STRING
F018 CD 3C 20    CALL  203C
F01B C9          RET

DEFB:-
F01C 10 09 11 08 12 00 13 00
F024 14 00 15 00
```

You can, of course, select what you want for your 'normal' attributes when you restore them at the end.

Now when you call the subroutine you will only have to specify the address: the subroutine will read off its own LEN$, for the control loop. You can group all the messages together in a block.

Notice, by the way, that you have to respecify the whole of BC, at F012h, as it gets corrupted by the 203Ch routine.

Stretching characters

Now, nice as all this is, it doesn't do very much. No sooner have new Spectrum owners run the 'Horizons' tape, than they wonder how they can get their Spectrum to print all shapes and sizes, like the tape.

In fact, the Psion machine code routine for stretching letters is a very good one and, as it is part of the Spectrum package, it is well worth pulling out of the cassette. It's not hard to write a little BASIC program to go with the routine to implement the magnified printing as required. However, the Psion routine is quite long and complicated and suffers from being, if anything, a bit too good. The choices are sometimes too many and too complicated.

For practical purposes, within the framework of an actual program, I find that the most useful enlarged character is one twice the linear size, which looks nice and bold, but is still small enough to display a good line of print (16 characters). But there are many useful variations. Let's see how these can be implemented.

To produce double-sized letters like the ones above, we have to make a block of four bits grow, where only one bit grew before. This means that, to make space for the big character, we shall have to spread it over four normal-sized characters, printed in a block. **Figure 3.3** shows what it will look like. In the inverse printing, you can see particularly well how the big

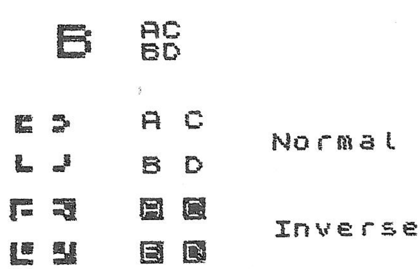


Figure 3.3: Large Graphics Character Made up of Four Normal-sized Characters

character is made up of four 'graphics' characters. This is in fact how the routine works. For every big character we print, we manufacture a set of four new graphics characters in UDG positions 'A', 'C', 'B' and 'D', and then print them out, as shown. (To save time, I'll be referring to the UDG positions by the names of the letters normally found there.)

In order to manufacture these graphic characters, we need a machine code routine. In principle it works quite simply.

First, we select the letter we want and look it up in the character set. Every character in the Spectrum character set is made up of eight bytes, each coding for a line of pixels on the screen. A set bit corresponds to a 'black' pixel: a zero bit corresponds to a 'white' pixel. For our purposes, we deal with the character four bytes at a time — the top half of the character first and then the bottom half.

First of all, we put the first byte of the chosen character into the A register. This is, in fact, the top line of the character. Unfortunately, the top line of the character consists only of zeros, so we will set up an arbitrary line (**Figure 3.4**) which shows the movements more clearly. (Actually, it is the second line, shifted two bits to the right.) We then PUSH bit 0 into the carry bit, by doing 'RRA' (rotate right A).

```
              76543210
              00011111     "A" register

    RRA >>>>

              76543210
              00001111  >  1  (Carry)
```

Figure 3.4

We choose the DE register pair to hold the two new bytes, which we are going to generate from the single byte in A and we shift the carry bit into the '7' position in the D register, with an 'RR D' (**Figure 3.5**). This action, of course, tips bit 0 of D back into the carry, so we pick that up again and get it into E, by doing 'RR E'.

```
              76543210
              00000000     "D" register

    RR D >>>>

              76543210
              10000000  >  0  (Carry)

    RR E >>>>

              76543210
         0 >  00000000  >  0  (Carry)
```

Figure 3.5

As the new character is going to be twice as thick as the old one, we need to double up on the new bit which we have taken from A. This can be done by using 'SRA D'. 'Shift right arithmetic' shifts all the bits along one place, but it also copies into the vacant position at 7 the value of the bit previously held there — which is exactly what we want. To complete the operation, we pick up the previous bit 0, which has dropped into the carry, by doing 'RR E' again (**Figure 3.6**).

```
              76543210
              10000000      "D" register
  SRA D >>>>
              76543210
              11000000  >  0  (Carry)
   RR E >>>>
              76543210
         0 >  00000000  >  0  (Carry)
```

Figure 3.6

You can see that, after doing this eight times, we shall have copied all the bits from A as double bits into D and E. All that remains now is to copy D and E into the appropriate bytes of UDG 'A' and 'C'.

Since our new characters will be twice as deep, as well as being twice as thick, we copy D and E for a second time, into the next two bytes of UDG 'A' and 'C': these will form the second line of the character on the screen (**Figure 3.7**).

```
  Original "A"  00111100

           00111111  11110000
           00111111  11110000
```

Figure 3.7

After four of these operations, we shall have finished the top half of the original character and will have filled all the bytes of UDG 'A' and 'C'. But, by continuing with the program, we transfer operations to UDG 'B' and 'D' and fill them with the bottom half of the original character, using the same technique.

Here is the completed listing. The operations between F000h and F00Fh are concerned with getting the character INPUT at the keyboard from the system variable LAST_K, and working out the address in the character set for this character in HL. The rest of the routine generates the four new graphic characters. Notice that, when finding the address for the UDG characters, we do it indirectly, through the system variable UDG at 5C7Bh. This allows you to select a different address, if you want to.

Double-sized Letters ✓

```
F000  21 00 00      LD    HL,0000       CLEAR HL
F003  3A 08 5C      LD    A,(5C08)      LAST_K
F006  D6 20         SUB   20            GET VALUE OF CHR CODE
F008  6F            LD    L,A             INTO HL
F009  29            ADD   HL,HL       }
F00A  29            ADD   HL,HL       } MULTIPLY BY 8
F00B  29            ADD   HL,HL       }
F00C  01 00 3D      LD    BC,3D00       START OF CHR SET
F00F  09            ADD   HL,BC         ADDRESS OF CHR
F010  DD 2A 7B 5C   LD    IX,(5C7B)     ADDRESS OF UDG
F014  0E 08         LD    C,08
F016  7E            LD    A,(HL)
F017  06 08         LD    B,08
F019  1F            RRA
F01A  CB 1A         RR    D
F01C  CB 1B         RR    E
F01E  CB 2A         SRA   D
F020  CB 1B         RR    E
F022  10 F5         DJNZ  F019
F024  DD 72 00      LD    (IX),D
F027  DD 72 01      LD    (IX+01),D
F02A  DD 73 10      LD    (IX+10),E
F02D  DD 73 11      LD    (IX+11),E
F030  23            INC   HL
F031  DD 23         INC   IX
F033  DD 23         INC   IX
F035  0D            DEC   C
F036  20 DE         JR     NZ,F016
F038  C9            RET
```

Here are two short BASIC programs, which make use of the double-sized letters routine. One allows you to type in the letters, as on a typewriter. The second prints out a string in the double-sized letters.

Notice that both programs get the required letter into LAST_K; program 1 from the keyboard and program 2 by POKEing the system variable directly. LAST_K is a very good access point for printing techniques which need an interface between a BASIC program and machine code. It is one of the easiest ways of picking up a character, even though it might seem a little indirect.

Type Double-sized Letters

```
100 LET x=0: LET y=0
110 PAUSE 0
120 IF CODE INKEY$=13 THEN LET x=0: LET
y=y+2: GO TO 110
130 RANDOMIZE USR 61440
140 PRINT BRIGHT 1;AT y,2*x;"[illegible]";AT y+1
,2*x;"[illegible]"
150 LET x=x+1
160 GO TO 110
```

Print String in ×2 Letters

```
 10 INPUT w$
100 LET x=0: LET y=0
110 FOR j=1 TO LEN w$
120 POKE 23560,CODE w$(j)
130 RANDOMIZE USR 61440
140 PRINT BRIGHT 1;AT y,2*x;"[illegible]";AT y+1
,2*x;"[illegible]"
150 LET x=x+1
160 NEXT j
```

Using the bones of these techniques, it's simple to devise routines which will generate tall or fat characters — characters which are twice as high, but of normal width, or twice as wide, but of normal height. It is a matter of omitting the unwanted half of the routine — either the 'double shuffle' through D and E, or the double loading of D and E into the graphics characters.

The main differences in these next two programs from the double-size routines come in the loop arrangements, as it is these which control the way in which the bits are presented for the new graphics. All three have identical opening sections to find the address of the wanted characters in the character set. I have addressed the character set indirectly, as well as the UDG, in case you want to use a character set of your own, at an address different from the Sinclair character set.

In the tall letters routine, we don't have to do any bit-shifting. We simply load each bit twice into side-by-side locations in the UDG, addressed by IX. When one UDG has been filled, the routine moves automatically on to the next one.

Tall Letters

```
F000 21 00 00       LD    HL,0000
F003 3A 08 5C       LD    A,(5C08)
F006 D6 20          SUB   20
F008 6F             LD    L,A
F009 29             ADD   HL,HL
F00A 29             ADD   HL,HL
F00B 29             ADD   HL,HL
F00C ED 4B 36 5C    LD    BC,(5C36)
F010 04             INC   B
F011 09             ADD   HL,BC

F012 DD 2A 7B 5C    LD    IX,(5C7B)
F016 06 08          LD    B,08
F018 7E             LD    A,(HL)
F019 DD 77 00       LD    (IX),A
F01C DD 77 01       LD    (IX+01),A
F01F 23             INC   HL
F020 DD 23          INC   IX
F022 DD 23          INC   IX
F024 10 F2          DJNZ  F018
F026 C9             RET
```

To generate the broad letters, we do the shift (as in the double-sized letters), but not the doubling up.

"Fatties"

```
F000 21 00 00       LD    HL,0000
F003 3A 08 5C       LD    A,(5C08)
F006 D6 20          SUB   20
F008 6F             LD    L,A
F009 29             ADD   HL,HL
F00A 29             ADD   HL,HL
F00B 29             ADD   HL,HL
F00C ED 4B 36 5C    LD    BC,(5C36)
F010 04             INC   B
F011 09             ADD   HL,BC

F012 DD 2A 7B 5C    LD    IX,(5C7B)
F016 0E 08          LD    C,08
F018 7E             LD    A,(HL)
F019 06 08          LD    B,08
F01B 1F             RRA
```

```
F01C CB 1A       RR   D
F01E CB 1B       RR   E
F020 CB 2A       SRA  D
F022 CB 1B       RR   E
F024 10 F5       DJNZ F01B
F026 DD 72 00    LD   (IX),D
F029 DD 73 08    LD   (IX+08),E
F02C 23          INC  HL
F02D DD 23       INC  IX
F02F 0D          DEC  C
F030 20 E6       JR    NZ,F018
F032 C9          RET
```

As a final addition to these routines which use shifts and rotations, here is a program to let you print in 'bold' letters. Bold type, among printers, is the name for letters which have thicker strokes than normal, so that they stand out strongly from the page. In this program, we get the same effect by rotating each byte of the letter and then ORing it with the original byte (see Chapter 6, Four-bit Characters Entry program). This has the effect of doubling any bits which are set, smudging, as it were, each line of the letter. As a change of pace, I have given the BASIC program in an LPRINT version.

Bold Printing

```
F000 21 00 00    LD   HL,0000
F003 3A 08 5C    LD   A,(5C08)
F006 D6 20       SUB  20
F008 6F          LD   L,A
F009 29          ADD  HL,HL
F00A 29          ADD  HL,HL
F00B 29          ADD  HL,HL
F00C ED 4B 36 5C LD   BC,(5C36)
F010 04          INC  B
F011 09          ADD  HL,BC

F012 ED 5B 7B 5C LD   DE,(5C7B)
F016 06 08       LD   B,08
F018 7E          LD   A,(HL)
F019 1F          RRA
F01A B6          OR   (HL)
F01B 12          LD   (DE),A
F01C 23          INC  HL
```

```
F01D 13          INC  DE
F01E 10 F8       DJNZ F018
F020 C9          RET
```

Print out in **Bold Letters**

```
 100 LPRINT "Print out in ";
 110 LET w$="Bold Letters"
 120 FOR j=1 TO LEN w$: POKE 23560,CODE
w$(j): RANDOMIZE USR 61440: LPRINT "■";:
 NEXT j
```

The bold version of each letter is loaded, once again, into the long-suffering UDG ‘A’.

And, of course, there are still further variations…

This is a line of DOUBLE BOLD!

The routine can also be adapted very simply to ‘embolden’ the entire screen. The reason you might want to do this is to fill in ‘pinholes’. Sometimes you put together a graphics routine which is supposed to fill in a solid figure — by generating a series of curves, for example, each offset from the last by one pixel. All too often these curves don’t quite overlap everywhere, leaving the pinholes. The smudging routine will usually fill them in. Here it is:

BOLD Screen

```
F000 21 00 40    LD   HL,4000
F003 01 00 18    LD   BC,1800
F006 7E          LD   A,(HL)
F007 1F          RRA
F008 B6          OR   (HL)
F009 77          LD   (HL),A
F00A 23          INC  HL
F00B 0B          DEC  BC
F00C 78          LD   A,B
F00D B1          OR   C
F00E 20 F6       JR   NZ,F006
F010 C9          RET
```

CHAPTER 4
Even Bigger Characters

To print the next size of letters (× 4, rather than × 2) calls for a rather different technique.

We could simply extend the rotating system, so as to produce four graphic characters per line rather than two. However, Sinclair have conveniently provided a complete set of 4 pixel by 4 pixel graphics. The only problem is to access the ones we want for each piece of our big character. And here, again, the way in which the Sinclair graphics are set out makes this exceptionally easy, as I'll explain.

Figure 4.1 shows the letter 'B' printed up with a grid, which breaks it up into the constituent Sinclair graphics.

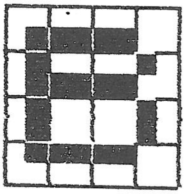


Figure 4.1

If you look at p.186 of the Sinclair manual, you will find that the graphics are spread between 128 and 143, which correspond to the hex notations '80 + 0' and '80 + F'. Now, if you number the four quarters of each character as in **Figure 4.2** you will find that the '+' number for each graphic character is always the sum of the numbers of the 'black' squares.

2	1
8	4

Figure 4.2

For example, the graphic character  (corresponding to the top lefthand corner of the big letter 'B' above) has the code 132, which is the same as 80h + 4, and '4' is the number in the righthand bottom corner of our numbered square. Similarly, the next along in the big 'B' has code 140, which is 80 + C, where 'C' is 12, the sum of the bottom two numbers.

It's extremely easy to calculate these numbers for each graphic character (it was, of course, designed to be!). For example, if you peel off bits 7 and 8 of the first byte of CHR 'B', you get '0 0'. Doing the same for the second byte yields '0 1'. Put them together in the order in which they are peeled off (right to left and bottom to top) and they wind up as '0 1 0 0' which (surprise, surprise!) has the value '4'.

Now we can put together a machine code routine to do this automatically for each block of four bits.

The trick is to get pairs of bytes from the character set into D and E, and then, with a couple of rotate operations, first for E and then for D, slide the four required bits, in the right order, into A. All we then have to do is to set bit 7 of A (which gives the '80+x' value, which applies to the grahics) — and print it.

The full routine is given below. Once again the instructions from F000h to F011h are concerned with getting the right address into HL.

The section from F02Ch to F03Bh takes care of moving the print position down one line and four columns to the left, so that the next group of four graphic characters is printed under the last. As we haven't done this before, I'll describe how it operates: it is a useful routine to have in hand. You will still, however, have to get your BASIC program to reassign the print position for each letter.

Bigger!

```
F000 21 00 00      LD   HL,0000
F003 3A 08 5C      LD   A,(5C08)
F006 D6 20         SUB  20
F008 6F            LD   L,A
F009 29            ADD  HL,HL
F00A 29            ADD  HL,HL
F00B 29            ADD  HL,HL
F00C ED 4B 36 5C   LD   BC,(5C36)
F010 04            INC  B
F011 09            ADD  HL,BC

F012 0E 04         LD   C,04
F014 06 04         LD   B,04
```

```
F016 56             LD    D,(HL)
F017 23             INC   HL
F018 5E             LD    E,(HL)

F019 23             INC   HL
F01A AF             XOR   A
F01B CB 13          RL    E
F01D 17             RLA
F01E CB 13          RL    E
F020 17             RLA
F021 CB 12          RL    D
F023 17             RLA
F024 CB 12          RL    D
F026 17             RLA
F027 CB FF          SET   7,A
F029 D7             RST   10
F02A 10 EE          DJNZ  F01A

F02C C5             PUSH  BC
F02D E5             PUSH  HL
F02E ED 4B 88 5C    LD    BC,(5C88)    S POSN
F032 05             DEC   B            NEXT LINE
F033 0C             INC   C
F034 0C             INC   C            BACK 4 COLS
F035 0C             INC   C
F036 0C             INC   C
F037 CD D9 0D       CALL  0DD9         SETS PR_POS
F03A E1             POP   HL
F03B C1             POP   BC

F03C 0D             DEC   C
F03D 20 D5          JR    NZ,F014
F03F C9             RET
```

To change the print position, you first have to find the *existing* position. The current column and line print positions are held in the system variable S_POSN. This holds the numbers we normally use when we print 'AT y,x', in the form 33−x and 24−y (where x = column and y = line). But, to change the print position, it is not enough simply to alter these two numbers — the system variable DF_CC has to be changed in step. This last holds the address in the display file of the first byte of the character — and, as we shall find to our cost, this is not the easiest number to calculate.

However, once we have the new values for S_POSN — which are quite easy to calculate — if we put them into BC and CALL the ROM routine at 0DD9h, this routine will calculate DF_CC and load all the system variables, as required.

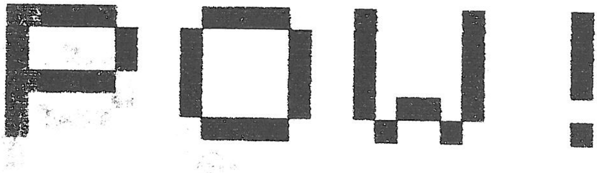
This can be very useful when planning machine code printing operations. Remember, it's (24 – line) into B; (33 – column) into C and then CALL 0DD9h. Most of the registers are altered by this operation, so be sure to PUSH and POP any that you want to keep.

The last of the 'big characters' I want to deal with increases the linear dimensions eight times. This uses a complete character square for every pixel of the original, which makes a big, bold character, but one you can only use sparingly — you can only get four into a line, after all.

This character is one of the easiest to generate, as we only have to run through the bytes for the character in order and arrange to print a black square, when a set bit is found, and a white square otherwise.

It is neater to use the 'graphic space' — CHR$ 80h — rather than the normal space, CHR$ 20h. The black square is CHR$ 8Fh, so it becomes a matter of changing the second nibble only to get the results we want. In the routine below, this is done at F017h–F01Fh, using the carry, generated by an RLA (rotate left A) operation, to jump over the operation not required.

The same technique for restoring the print position is used, but now we have to move it back *eight* positions and down *one*.



```
F000 21 00 00      LD   HL,0000
F003 3A 08 5C      LD   A,(5C08)
F006 D6 20         SUB  20
F008 6F            LD   L,A
F009 29            ADD  HL,HL
F00A 29            ADD  HL,HL
F00B 29            ADD  HL,HL
F00C ED 4B 36 5C   LD   BC,(5C36)
F010 04            INC  B
F011 09            ADD  HL,BC

F012 0E 08         LD   C,08
F014 06 08         LD   B,08
F016 7E            LD   A,(HL)
```

```
F017 23          INC  HL
F018 17          RLA
F019 F5          PUSH AF

F01A 3E 80       LD   A,80      GRAPHIC 'SPACE'
F01C 30 02       JR    NC,F020
F01E C6 0F       ADD  A,0F      GRAPHIC 'BLACK SQUARE'
F020 D7          RST  10        PRINT
F021 F1          POP  AF
F022 10 F4       DJNZ F018

F024 C5          PUSH BC
F025 E5          PUSH HL
F026 ED 4B 88 5C LD   BC,(5C88)
F02A 05          DEC  B         NEXT LINE
F02B 79          LD   A,C   }
F02C C6 08       ADD  A,08  }   BACK 8 COLS.
F02E 4F          LD   C,A   }
F02F CD D9 0D    CALL 0DD9
F032 E1          POP  HL
F033 C1          POP  BC

F034 0D          DEC  C
F035 20 DD       JR    NZ,F014
F037 C9          RET
```

Since we are now dealing with complete print positions to build up our big characters, there is no reason why we should not get the same effect by using the attributes file, rather than the display file, to hold the enlarged graphics. The routine needs very little alteration — just setting up the address in the attributes file in DE and doing the re-addressing between lines by a simple addition, rather than the ROM routine used for the display file.

×8 Letters with Attributes only

```
F000 21 00 00    LD   HL,0000
F003 11 18 58    LD   DE,5818
F006 3A 08 5C    LD   A,(5C08)
F009 D6 20       SUB  20
F00B 6F          LD   L,A
F00C 29          ADD  HL,HL
F00D 29          ADD  HL,HL
F00E 29          ADD  HL,HL
F00F 01 00 3D    LD   BC,3D00
```

```
F012 09          ADD  HL,BC

F013 0E 08       LD   C,08
F015 06 08       LD   B,08

F017 7E          LD   A,(HL)
F018 23          INC  HL
F019 17          RLA
F01A F5          PUSH AF
F01B 3E 00       LD   A,00        INK 0; PAPER 0
F01D 38 02       JR     C,F021
F01F 3E 3F       LD   A,3F        INK 7; PAPER 7
F021 12          LD   (DE),A
F022 13          INC  DE
F023 F1          POP  AF
F024 10 F3       DJNZ F019

F026 C5          PUSH BC
F027 EB          EX     DE,HL
F028 01 18 00    LD   BC,0018     (32 - 8) PRINT POSITIONS
F02B 09          ADD  HL,BC
F02C EB          EX     DE,HL     INTO DE
F02D C1          POP  BC

F02E 0D          DEC  C
F02F 20 E4       JR     NZ,F015
F031 C9          RET
```

The fact that we are not using the display file, even though the result looks like printing, opens up some curious and interesting possibilities. If, when you have entered the machine code routine above, you can bring yourself to enter the rather shaming little program below and RUN it, with the printer hooked up, you will get a result which, though predictable, still makes you think....

More of these uses of the attributes and display file in a later chapter.

Peekaboo

```
  10 PRINT AT 3,10;"Peekaboo!"
  20 LET w$="POW!"
  30 FOR j=1 TO LEN w$: POKE 23560,CODE
w$(j)
  40 POKE 61440,(j-1)*8: RANDOMIZE USR 6
1440: NEXT j
  50 PAUSE 0
  60 COPY
```

CHAPTER 5
Sideways Characters

New character sets

There are a number of other variations on the Spectrum printing schemes which we can try out. So far, we have only considered techniques which produce letters in an *ad hoc* way, as they are needed for the display. This is perfectly adequate when the new lettering is needed only now and then, but the routines tend to be on the slow side, as they work a letter at a time, and this could be a disadvantage if you wanted to produce large parts of the display in the new lettering.

The new letterings we shall be discussing now are better adapted to use as completely new character sets, created in advance. They can be used as required, by POKEing the system variable CHARS with the new address *minus* 100h (256d). The set in the ROM can always be recovered by POKEing the same variable with its usual address, 3C00h. (The actual character set starts at 3D00h.)

One feature which all of these new sets of characters have in common is that they are all based on the existing Spectrum set: I am not suggesting that you should laboriously type in 96 or so new characters, each of eight bytes. Life is too short. The object of the present chapter will be to show you how to write programs which will generate new character sets on the basis of the old.

Sideways characters

The first altered character set I want to consider is one which uses the ordinary Spectrum letters, but prints them on their sides.

This can be very useful if you want to present results graphically, for business or scientific purposes. It is an absolute must if you have a horizontally-scrolling display, which needs to carry a title at some single location. **Figure 5.1** shows the sort of thing I mean.

In fact, the 'sideways characters' *can* be generated one at a time, as we have been doing so far. But if you have space to spare in RAM for a complete character set (it takes 300h (768d) bytes) this is much quicker and easier to operate.

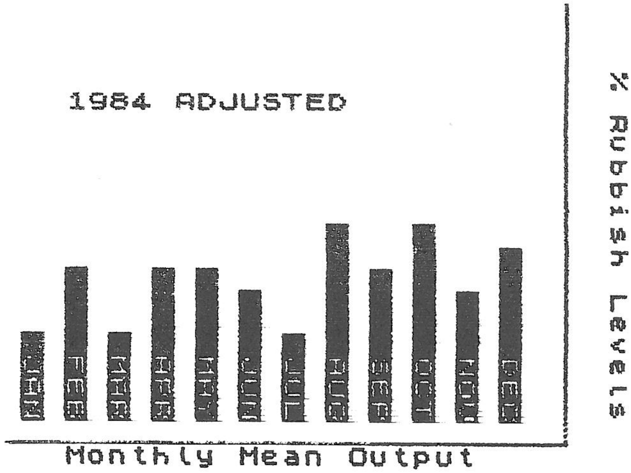


Figure 5.1: Sideways Character Set

First of all, let's look at what we have to do and how we are going to do it.

Turning letters on their sides

As we know, a character is made up of eight bytes, each coding for a line of the printed character. Capital 'A' looks like **Figure 5.2**.

0	0	0	0	0	0	0	0	Byte 1 - 00
0	0	1	1	1	1	0	0	Byte 1 - 3C
0	1	0	0	0	0	1	0	Byte 1 - 42
0	1	0	0	0	0	1	0	Byte 1 - 42
0	1	1	1	1	1	1	0	Byte 1 - 7E
0	1	0	0	0	0	1	0	Byte 1 - 42
0	1	0	0	0	0	1	0	Byte 1 - 42
0	0	0	0	0	0	0	0	Byte 1 - 00

Figure 5.2: Capital 'A'

To lay the 'A' on its side, we have to strip off the matching bits from each byte, one at a time, and re-form them into eight new bytes, which will look like **Figure 5.3**.

```
0 0 0 0 0 0 0 0   Byte 1 - 00
0 1 1 1 1 1 0 0   Byte 1 - 7C
0 0 0 1 0 0 1 0   Byte 1 - 12
0 0 0 1 0 0 1 0   Byte 1 - 12
0 0 0 1 0 0 1 0   Byte 1 - 12
0 0 0 1 0 0 1 0   Byte 1 - 12
0 1 1 1 1 1 0 0   Byte 1 - 7C
0 0 0 0 0 0 0 0   Byte 1 - 00
```

Figure 5.3: Capital 'A' on its Side

You can see that the first byte of the new character is a line of zeros corresponding to the lefthand column of bits in **Figure 5.2**. Byte 2 in **Figure 5.3** corresponds to the second column of bits in **Figure 5.2**, and so on.

What this means, in programming terms, is that we have to rotate each of the original bytes in turn, so as to shed a bit at a time into the carry. Each time we do this, we scoop up the carry and transfer it to the new byte, which we are building up.

To do these operations, we have to have a scratch-pad: it is impossible to do any rotations, or other operations, in the ROM. So the first move is to transfer all eight bytes of the original character to a new address (I suggest MEM, the Spectrum calculator memory location, which is as handy as any). Supposing the address of our character at MEM is in HL, we can do an 'RL (HL)', followed by 'INC HL', followed by 'RRA' — and then repeat this seven more times. This will give us our new byte in the A register.

Here is the relevant listing (HL holds the address of the character in the ROM):

Single Sideways Letter

```
F010 11 92 5C    LD    DE,5C92
F013 D5          PUSH  DE
F014 01 08 00    LD    BC,0008
F017 ED B0       LDIR            GET CHR INTO SCRATCH-PAD
F019 E1          POP   HL        SCRATCH-PAD ADDR INTO HL

F01A 11 58 FF    LD    DE,FF58   UDG 'A'
F01D 0E 08       LD    C,08
F01F 06 08       LD    B,08
```

```
F021  E5          PUSH  HL
F022  CB 16       RL    (HL)
F024  23          INC   HL
F025  1F          RRA
F026  10 FA       DJNZ  F022
F028  12          LD    (DE),A     LOAD NEW BYTE INTO UDG
F029  13          INC   DE
F02A  E1          POP   HL         BACK TO START OF
F02B  0D          DEC   C          SCRATCH-PAD
F02C  20 F1       JR      NZ,F01F
F02E  C9          RET
```

To do our usual 'one off' transformation, we just have to add the standard opening, which recovers the code of the character from LAST_K.

Sideways Printing

```
F000  21 00 00    LD    HL,0000
F003  3A 08 5C    LD    A,(5C08)
F006  D6 20       SUB   20
F008  6F          LD    L,A
F009  29          ADD   HL,HL
F00A  29          ADD   HL,HL
F00B  29          ADD   HL,HL
F00C  01 00 3D    LD    BC,3D00
F00F  09          ADD   HL,BC
F010  11 92 5C    LD    DE,5C92
F013  D5          PUSH  DE
F014  01 08 00    LD    BC,0008
F017  ED B0       LDIR
F019  E1          POP   HL
F01A  11 58 FF    LD    DE,FF58
F01D  0E 08       LD    C,08
F01F  06 08       LD    B,08
F021  E5          PUSH  HL
F022  CB 16       RL    (HL)
F024  23          INC   HL
F025  1F          RRA
F026  10 FA       DJNZ  F022
F028  12          LD    (DE),A
F029  13          INC   DE
F02A  E1          POP   HL
F02B  0D          DEC   C
```

```
F02C 20 F1        JR    NZ,F01F
F02E C9           RET
```

To create the complete character set, we need an address at which to start the new set, and we also need to make a few modifications to the routine.

It's a good plan to start the new characters at an address ending in '00'. This is because the ROM set starts at 3D00h, so, if the new address also has '00' as its second byte, we only have to alter the first byte to swap addresses. This means changing the number held at 5C37h (CHARS + 1, 23607d) in order to switch the sets. I have suggested 'E000h'.

We use the alternate registers to hold the overall count for the total number of characters in the set — 60h, or 96d — and also to handle the transfer from ROM to scratch-pad for each letter. Notice in the listing how the first action on moving into the alternate registers is to 'PUSH HL': the final action before leaving them for the last time is to 'POP HL' again. This preserves the important address held there by the Spectrum for its own business. Notice also how, after each transfer to the scratch–pad, HL conveniently points to the next letter, because it has been moved up by the 'LDIR' instruction.

Sideways Character Set

```
F000 11 00 E0     LD    DE,E000    START ADDRESS NEW CHRS
F003 D9           EXX
F004 E5           PUSH  HL
F005 06 60        LD    B,60
F007 21 00 3D     LD    HL,3D00    START ADDRESS ROM CHRS
F00A C5           PUSH  BC
F00B 11 92 5C     LD    DE,5C92    SCRATCH-PAD
F00E 01 08 00     LD    BC,0008
F011 ED B0        LDIR
F013 D9           EXX
F014 21 92 5C     LD    HL,5C92    SCRATCH-PAD
F017 0E 08        LD    C,08
F019 06 08        LD    B,08
F01B E5           PUSH  HL
F01C CB 16        RL    (HL)
F01E 23           INC   HL
F01F 1F           RRA
F020 10 FA        DJNZ  F01C
F022 12           LD    (DE),A
```

```
F023 13          INC  DE
F024 E1          POP  HL
F025 0D          DEC  C
F026 20 F1       JR    NZ,F019

F028 D9          EXX
F029 C1          POP  BC
F02A 10 DE       DJNZ F00A        JUMP TO NEXT CHR

F02C E1          POP  HL
F02D D9          EXX

F02E C9          RET
```

Once the routine has been entered and RUN, you will create a complete new character set starting at E000h. If you write a BASIC program and incorporate the line 'POKE 23607,223' (= DFh, 100h — or 256d less than the start address for the characters) everything you print will be sideways.

But remember to incorporate 'POKE 23607,60' somewhere, or you may be stranded with some very odd listings (see **Figure 5.4**)!

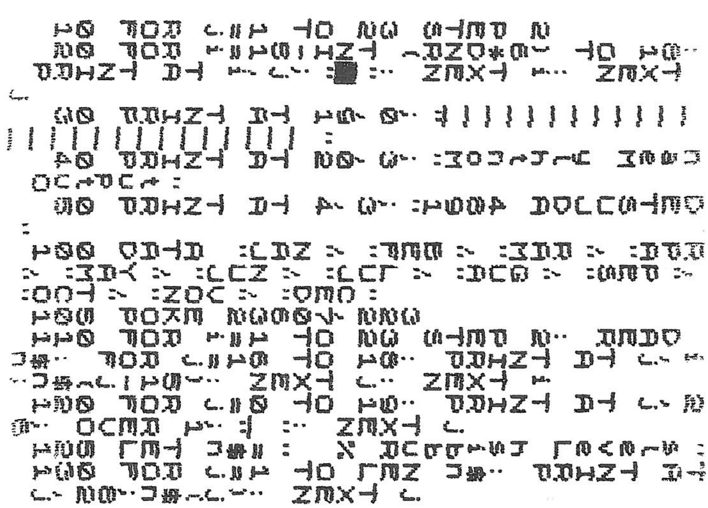


Figure 5.4

One final point — the key operations are 'RL (HL)' and 'RRA'. By changing these, you alter the sequence in which the bytes are stripped and re-assembled, so that you can make the letters face in various different directions, though always on their sides. **Figure 5.5** shows the four possible configurations, two mirror–image and two normal.

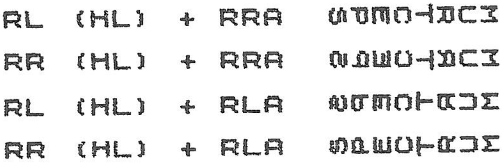


Figure 5.5: Letters Facing in Various Directions

CHAPTER 6
Small Characters

As I pointed out earlier, the Spectrum character set uses a good many more bits than are absolutely necessary to produce a legible set of characters. By reducing the number of bits used horizontally to produce a character — that is, by squeezing the character sideways — we should, theoretically, be able to print more characters per line. This could be a big advantage, especially when we all get our Microdrives and have plenty of memory to splash about in.

One of the things we would like to do would be to enter sizeable chunks of text, but, even if we get them into memory, when printed out at 32 characters per line we can't get much on to the screen. It becomes more like reading a telegram than a page of print.

Six-bit characters

It is really quite simple to produce squashed-up versions of the standard Spectrum character set. You can generate the new set by picking out just six (let us say) of the eight available bits, which make up each line of a character (**Figure 6.1**).

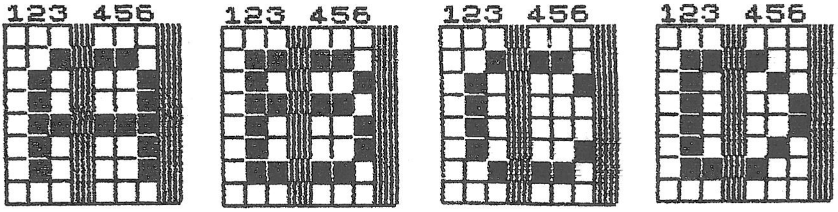


Figure 6.1

The standard last bit is always blank, anyway, so you are really only scrapping one bit per byte. **Figure 6.2** is a complete set of capital letters, generated in this way. They look quite convincing, with the exception of

Figure 6.2

the 'T' and the 'Y', which have suffered serious losses, and the 'I' which is lop-sided.

The machine code principle behind the making of these letters lies with our old friends, the 'rotates' and the 'shifts'. The routine gets each byte of the standard characters into the A register and then slides off the component bits, one by one, into the carry. Then it picks up the bits needed for the new character from the carry and transfers them to a waiting byte at a new address, which is addressed by HL.

6-bit Characters

```
F000 11 00 3D    LD    DE,3D00
F003 21 00 E0    LD    HL,E000
F006 01 00 03    LD    BC,0300
F009 1A          LD    A,(DE)
F00A 07          RLCA
F00B CB 16       RL    (HL)
F00D 07          RLCA
F00E CB 16       RL    (HL)
F010 07          RLCA
F011 CB 16       RL    (HL)
F013 07          RLCA
F014 07          RLCA
F015 CB 16       RL    (HL)
F017 07          RLCA
F018 CB 16       RL    (HL)
F01A 07          RLCA
F01B CB 16       RL    (HL)
F01D CB 26       SLA   (HL)
F01F CB 26       SLA   (HL)
F021 ED A0       LDI
F023 E0          RET   PO
F024 18 E3       JR    F009
```

The automatic loading instruction 'LDI' is ideal for this, as it both 'increments' the HL and DE registers and 'decrements' the count in BC.

While the capital letters — and even the numerals — can be transformed quite effectively using this particular mix of bits, the lower case letters don't do quite as well (**Figure 6.3**): 'a' and 'b' are all right, but as for 't' and 'f' — oh dear!

I was, in fact, exaggerating a little when I said that all these characters could be generated automatically from the original Sinclair set. Most of them can be, but there will always be mavericks which will have to be adjusted individually.

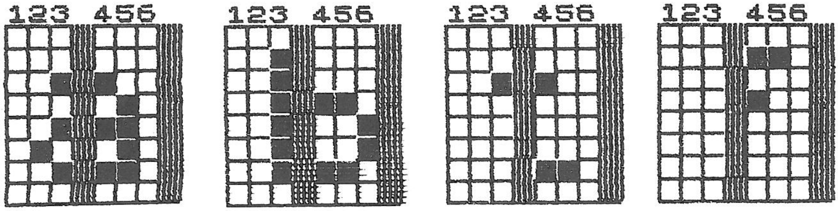


Figure 6.3

To do the adjusting, I have devised a program called Titivator which will let you refurbish any character you want to, once you have automatically generated the rough versions starting at E000h. The program will display enlarged versions of any of the new characters you choose and will let you enter the binary codes of each line, so as to build up a revised character. **Figure 6.4** shows how the display appears.

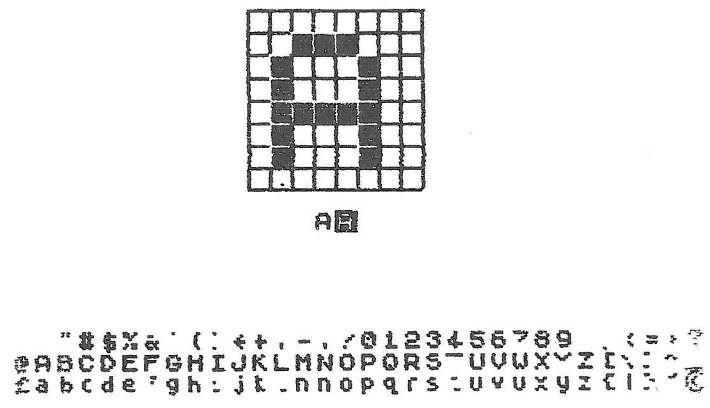


Figure 6.4

A single keystroke will display your chosen letter, enlarged and normal size (in true and inverse video) with the complete character set below that. If you want to alter a character, you can do so by keying in ENTER, when you will be able to enter each line (ie byte) in turn, in binary. (You need not enter all the terminal zeros — '0101' is the same as '01010000'.) Before writing the program, you must put the code for '×8 Letters' (at the end of Chapter 4) into a REM statement, in line 1 (this will take 54 spaces). Then fill in the rest of the BASIC program.

Titivator

```
5 POKE 23660,5
6 POKE USR "a",255: FOR j=1 TO 7: POK
```

```
E USR "a"+j,128: NEXT j
   7 POKE USR "b",255: FOR j=1 TO 7: POK
E USR "b"+j,0: NEXT j
   8 FOR j=0 TO 7: POKE USR "c"+j,128: N
EXT j
   9 INPUT "INPUT start of new character
 set";ad: LET ad=ad-256: LET ad2=INT (ad
/256): LET ad1=ad-256*ad2
  10 PRINT #1;AT 0,0;"Character?": PAUSE
 0: LET y$=INKEY$: PRINT #2
  20 IF CODE y$=13 THEN GO TO 200
  25 LET chr=CODE y$
  30 POKE 23606,ad1: POKE 23607,ad2: POK
E 23560,chr
  50 LET z$="[illegible]"
  60 FOR j=0 TO 7: PRINT AT 2+j,11;z$: N
EXT j
  70 PRINT AT 10,11;"[illegible]"
  80 PRINT OVER 1;AT 2,11;: RANDOMIZE US
R (5+PEEK 23635+256*PEEK 23636)
  90 PRINT AT 11,14;CHR$ chr; INVERSE 1;
CHR$ chr
 100 PRINT AT 18,0;: FOR j=32 TO 127: PR
INT CHR$ j;: NEXT j
 110 POKE 23606,0: POKE 23607,60
 120 GO TO 10
 200 DIM b$(8)
 210 FOR j=0 TO 7
 220 INPUT "Line No:";(j+1);" BIN ";b$
 230 IF b$(1)<>"0" AND b$(1)<>"1" THEN S
TOP
 240 LET x=0: FOR i=1 TO 8: LET x=x*2+(b
$(i)="1"): NEXT i
 250 POKE ad+256+8*(chr-32)+j,x
 260 NEXT j
 270 GO TO 30
```

I don't think that the BASIC program should be puzzling, but here are a few notes.

Line 5: Stops the automatic listing from getting bogged down with an 'unlistable' line 1, due to the machine code. It POKEs the system variable 'S_TOP' with a number greater than 1.

Lines 6–8: Generate the UDGs to draw a grid on the enlarged letter.

Line 10: Changes the channel so as to print on the lower screen, and then changes it back again.

Line 30: Switches to the new character set (at 57344d) and places the required character CODE in 'LAST_K'.

Lines 50–70: Print the grid.

Line 80: Gets the start of the machine code program. The address of the BASIC program, in the system variable PROG, can change, although in practice it always stays the same unless the Interface 1 is connected. Without the interface, you could make it 'RANDOMIZE USR 23760', but it is probably safer to use the indirect addressing.

Line 110: Switches back to normal characters.

Figure 6.5 shows what the six-bit character set looks like after half an hour with Titivator. It is greatly improved. I leave it to you to attend to the punctuation marks etc....

Figure 6.5: Six-bit Character Set

As it stands, the new set has no advantages over the old, because each letter still occupies a full eight-bit print position. We still need to reduce the spacing between the letters. This can be done, but it needs some solid machine code programming, which is better left to the next chapter. In the meantime, let's look at another character set which is, if anything, handier than the six-bit set — the four-bit set.

Four-bit characters

It may seem surprising, but you can generate letters using only a width of *three bits*, plus an extra bit for the space between letters. They may not be the prettiest letters in the world, but you can read them, and you can get a full 64 letters to the standard Sinclair line! That's as many as on a normal printed page. See **Figure 6.6**.

The beauty of this particular system is that two four-bit letters fit neatly into a single eight-bit print position. And the double character can be produced quite easily with a little ANDing and ORing, as we shall see.

But first, let's generate the characters.

```
This is an example of printing, using a 4-Bit Character set.
It is, really, quite readable and allows one to enter a full-
length line of text, using the normal Sinclair SPECTRUM display
facilities.

Each character uses only three Bits, horizontally,with the 4th
Bit as a standard space between letters.

A full set of characters can be generated, together with the
numerals, 0123456789, and the usual punctuation marks.
```

Figure 6.6: Four-bit Characters

The machine code listing is very much the same as that for the six-bit characters. However, since we have only three bits to play with, the selection of the right three bits has to be judicious. In fact, I find that it's best to take two bites (no pun intended) — the first selection to cover the lower case letters and the second for the capitals and numerals. For the other characters, you must judge for yourself.

Here is the listing which I have found best for lower case letters.

Four-bit Characters

```
F000 11 00 3D     LD    DE,3D00
F003 21 00 FC     LD    HL,FC00
F006 01 00 03     LD    BC,0300
F009 AF           XOR   A
F00A 77           LD    (HL),A
F00B 1A           LD    A,(DE)
F00C 07           RLCA
F00D CB 16        RL    (HL)
F00F 07           RLCA
F010 CB 16        RL    (HL)
F012 07           RLCA
F013 07           RLCA
F014 CB 16        RL    (HL)
F016 07           RLCA
F017 07           RLCA
F018 CB 16        RL    (HL)
F01A 07           RLCA
F01B ED A0        LDI
F01D E0           RET   PO
F01E 18 E9        JR     F009
```

There are two things to note here. First, I suggest placing the new character set at FC00h: since you will be using 300h bytes, this is about as high as you can get without crashing the UDGs. You will want to save the set once it is made, probably with the operating program, and it is more convenient to save a chunk of data up to the top of RAM.

The second small point is that I have incorporated two instructions, at F009h and F00Ah, which clear the byte you are going to use in HL. If you don't do this, you will wind up with pieces of whatever was there before, incorporated in your characters.

Figure 6.7 shows what the set looks like after the first operation, if you have got Titivator in place, with line 30 reading 'POKE 23607,251...'.

Figure 6.7

To get the capitals and numerals, switch the instructions at F018h and F01Ah, so that they read 'RLCA RL (HL)', rather than 'RL (HL) RLCA'. You'll also have to make line F006h read 'LD BC,0200h'.

After running the routine, your combined set should now look like **Figure 6.8**: a bit rough here and there, perhaps, but beginning to be recognisable and readable.

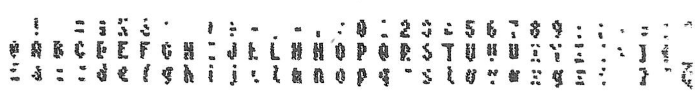


Figure 6.8

After a final session on Titivator, you might wind up with something like **Figure 6.9**. It will never be perfect, of course. The most difficult letters to manage are, 'H', 'M', 'N, 'W', 'n' and 'm'. There simply isn't enough information in three bits to differentiate them. You have to cheat, and trust that people's eyes will see what they expect to see — and, by and large, they do.

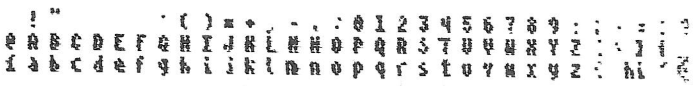


Figure 6.9

Here are my designs for the problem letters (**Figure 6.10**); they look very unconvincing when enlarged, but work pretty well in a piece of text. You may consider that some variations on these would look better.

Having achieved your four-bit character set and stored it safely on a cassette, you have next to consider how to use it.

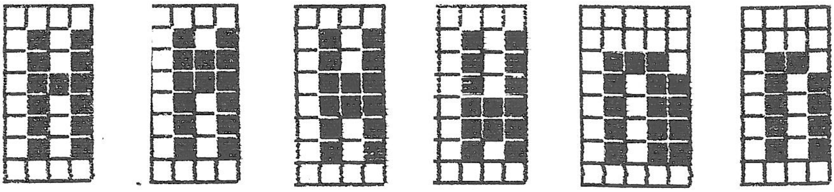


Figure 6.10: Designs for Problem Letters

There are various options. You may want to use the characters to print out text, or data, which you have stored in the RAM. You may want to use the letters as part of a system for inputting text to the RAM. You might even combine the two and have the elements of a word processor.

We'll consider only the first option here, printing out text. I've called this 'Typewriter'.

Typewriter

Here, we have to pick up letters from the keyboard, as we have done before, find their address in the character set, and then...

And then comes a difference from what we did before. We have to find some way of making a composite character out of two consecutive keystrokes. To do this, it is simplest to split the program into two parts. A subroutine, called from the main part, finds the character (and looks after a few other things, like breaking out of the program and coping with erasures and line feeds). The main routine combines the characters and prints them.

The subroutine has the most familiar material, so let's deal with it first.

Four-bit Characters — subroutine

```
F130 FD CB 01 AE RES  5, (IY+01)
F134 FD CB 01 6E BIT  5, (IY+01)
F138 28 FA       JR     Z,F134
F13A 3A 08 5C    LD   A,(5C08)

F13D FE 5E       CP   5E          BREAK KEY = '↑'
F13F C8          RET   Z

F140 FE 0D       CP   0D          NEW LINE
F142 28 2B       JR     Z,F16F

F144 FE 0C       CP   0C          BACKSPACE
```

```
F146 28 12         JR   Z,F15A

F148 FE 06         CP   06         CAPS SET
F14A 28 19         JR   Z,F165

F14C D6 20         SUB  20         )
F14E 6F            LD   L,A        |
F14F 26 00         LD   H,00       |
F151 29            ADD  HL,HL      |
F152 29            ADD  HL,HL      } FIND CHR ADDRESS
F153 29            ADD  HL,HL      |
F154 01 00 FC      LD   BC,FC00    |
F157 09            ADD  HL,BC      |
F158 0C            INC  C          )
F159 C9            RET

F15A 3E 08         LD   A,08       BACKSPACE
F15C D7            RST  10
F15D 3E 20         LD   A,20       'SPACE'
F15F D7            RST  10
F160 3E 08         LD   A,08       BACKSPACE
F162 D7            RST  10
F163 18 0B         JR   F170

F165 3A 6A 5C      LD   A,(5C6A)
F168 EE 08         XOR  08         SET/RESET CAPS LOCK
F16A 32 6A 5C      LD   (5C6A),A
F16D 18 C1         JR   F130

F16F D7            RST  10
F170 E1            POP  HL         DISCARD RETURN ADDRESS
F171 C3 00 F1      JP   F100
```

The first four instructions are a 'wait for a key' routine. This is a machine code alternative to the BASIC 'PAUSE 0', etc., which we used in the demonstration programs earlier. It works by first resetting byte 5 of the system variable FLAGS at 5C3Bh (23611d). As the IY register in the Spectrum normally always holds the address 5C3Ah, all the system variables can be accessed as offsets from this base.

Next, bit 5 of FLAGS is tested repeatedly. As long as no key has been struck, bit 5 remains zero, but, as soon as there is a key input, the bit gets changed to '1' and the 'JRZ' fails, so that the A register gets loaded from LAST_K (5C08h).

What we've discussed here is another handy little routine to allow you to access the keyboard.

Immediately after this, the routine tests for four special cases, which sort out four individual key codes for attention elsewhere.

5E — I have chosen as the BREAK key. It is ' ↑ ' and, by holding on to the zero flag, when the input subroutine returns to the main routine, it will cause a RETURN from the entire program.

0D — is the code for ENTER — or new line/carriage return. It simply prints itself (which gives the new line) and jumps back to the start of the main routine. This is done by POPping the normal address off the stack and doing a straight jump.

0C — is the code for DELETE. When this is matched, the routine jumps to F15Ah. Here, the routine first prints a backspace (code 8, cursor left), then prints a space, to blot out whatever was there before, and finally backspaces again, to restore the print position. The routine then jumps back to the start, using the same route as before.

06 — this, to my surprise, is the code from CAPS LOCK. The routine jumps to do precisely that — locking, or unlocking, the CAPS LOCK by an XOR operation (see later in this chapter). Then it jumps back to the start, to see what you actually want to print.

The rest of the subroutine from F14Ch, should be familiar, too. It calculates the address of the character in the new character set and returns with this information to the main routine.

The main routine CALLs the subroutine twice — once for each of the characters which make up the composite 'double character'. As so often, these characters are put together in the UDG. Here is the listing.

Four-bit Characters Entry Code — main routine

```
F100 11 58 FF     LD    DE,FF58    UDG 'A'

F103 CD 30 F1     CALL  F130       SUBROUTINE
F106 C8           RET    Z         BREAK-ROUTINE ENDS

F107 06 08        LD    B,08
F109 7E           LD    A,(HL)
F10A 07           RLCA
F10B 07           RLCA
F10C 07           RLCA
F10D 07           RLCA
F10E 12           LD    (DE),A
F10F 13           INC   DE
F110 23           INC   HL
F111 10 F6        DJNZ  F109
```

```
F113 3E 90      LD    A,90
F115 D7         RST   10        PRINT UDG 'A'
F116 3E 08      LD    A,08
F118 D7         RST   10        PRINT BACKSPACE

F119 11 58 FF   LD    DE,FF58
F11C CD 30 F1   CALL  F130      SUBROUTINE
F11F C8         RET    Z        BREAK-ROUTINE ENDS

F120 06 08      LD    B,08
F122 1A         LD    A,(DE)
F123 B6         OR    (HL)      COMBINE TWO CHARACTERS

F124 12         LD    (DE),A
F125 13         INC   DE
F126 23         INC   HL
F127 10 F9      DJNZ  F122
F129 3E 90      LD    A,90
F12B D7         RST   10        PRINT UDG 'A'
F12C 18 D2      JR     F100
```

Both halves of the main routine start by getting the address for UDG 'A' into DE. Then they CALL the subroutine.

The subroutine is arranged so that it only returns with the zero flag set, if the BREAK character has been found. In all other cases, the flag is reset. The 'INC C' at F158h has no other purpose but to ensure that the zero flag is not set when the subroutine returns.

If the zero flag *has* been set, the 'RET Z' instruction ensures that we drop out of the program.

If all is well, the first part of the main program then eases our four-bit character over into the left-hand nibble and loads it into UDG 'A'. (There is, of course, nothing magical about UDG 'A'; it could equally well be UDG 'U', or any of the other UDG characters.) The program then prints the new character and immediately prints a backspace, so as to restore the print position.

In the second half of the program, which deals with the next character input, we fetch the eight bytes for the first four-bit character in DE, OR them with the new character in HL, and load the result back into DE. This is UDG 'A', which we print again. Then we jump back, to start all over again.

The effect on the screen is that of printing each four-bit character in turn. The DELETEs and 'new lines' work much as you would expect, except that the DELETE rubs out two characters at a time, because it can only deal with a complete print position.

Logical operations

The logical ORing, as carried out by the microprocessor, is a neat way of combining the two characters. Two letters, when they are ready to be brought together, look like **Figure 6.11**.

Figure 6.11

The 'G' has been shifted over to the left by the operations at F10Ah to F10Dh. It is now in the UDG, addressed by DE. The 'H' is in the new character set, addressed by HL. The A register picks up the letter 'G', a byte at a time, and compares it with the corresponding byte, held in HL.

The two first bytes aren't much use for looking at, as they are both blank, but if we take byte 1:

A holds 0010 0000 (HL) is 0000 0101

The OR operation, here, is exactly what it sounds like—the two bytes are compared and, if (HL) *or* A have a bite set in a particular position, then the final bit will be set, too. So the final byte — still in A — will be

0010 0101

This is loaded back into DE, to replace the existing character. (For the sake of interest, if we had been ANDing, then both (HL) *and* A would have to have a bit set in the same position for the final bit to be set. In this case, the final byte would have been '0000 0000'.)

When all the bytes in both characters have been ORed together, the result will look like **Figure 6.12**.

As we are discussing logical operations, we might just look at the XOR which I said, rather airily, a few pages back, was used to set, or reset the CAPS LOCK.

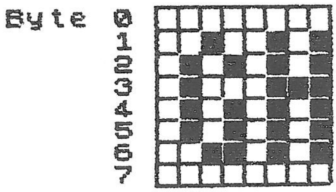


Figure 6.12

The operation in question went like this:

Set/Reset CAPS LOCK

```
F165 3A 6A 5C     LD    A,(5C6A)
F168 EE 08        XOR   08
F16A 32 6A 5C     LD    (5C6A),A
```

A collects the byte from the system variable FLAGS2 at 5C6Ah (23658d). Bit 3 of this byte controls the CAPS LOCK; it's *on* if the bit is set, *off* if it's not set. Let's assume it is not set at the moment, so the byte will look like this:

xxxx 0xxx

('x' means that we don't know, or care, what is going on in that particular bit.)

Now, we are going to XOR it with 08, which is,

0000 1000

At this point, XOR works just like an OR operation: that is, if the byte in A *or* the other byte have a bit set, the final bit will be set, too. So our final byte will be,

xxxx 1xxx

We load it back to the system variable and hey presto! WE ARE IN CAPITALS!

But now what happens when we do it again, next time round? XOR is not the same as OR: if *either* the bit in A *or* the corresponding bit is set, the final bit will be set. But *not if they are both set* — then XOR resets the bit. So when 'xxxx 1xxx' is put up against '0000 1000' and XORed, you finish with 'xxxx 0xxx' — and we are back in lower case again.

The 'x' bits always remain unaffected, because they are XORed with 0, so they will be set or reset only according to the contents of the byte in A.

You can see that the XOR operation is a classic way of switching bits on and off in the course of a program.

CHAPTER 7
Printing Six-bit Characters

Printing six-bit letters so as to display them at 40 characters to the line is rather more complex. They have to occupy three-quarters of the space, as compared to a normal eight-bit letter. The illustrations will make it clear what we are up against.

Figure 7.1 shows the letters, as stored in the new character file.

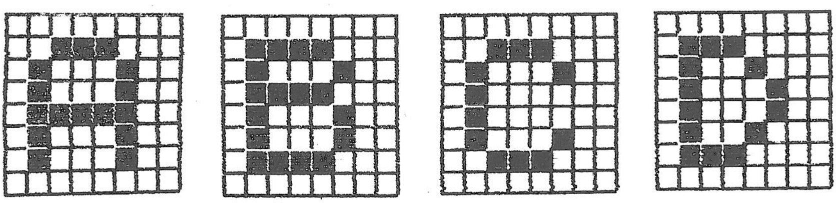


Figure 7.1

We need to rearrange a block of four letters, so that it is printed like **Figure 7.2**.

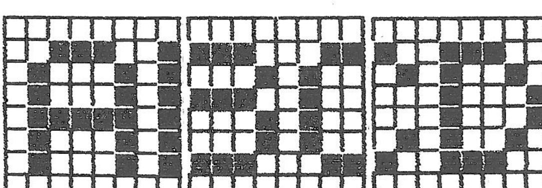


Figure 7.2

First, you must realise clearly that there is no way, on the Spectrum, that you can directly print a character offset to the left or right. The print positions are laid down hard and fast.

To print a character which is laterally offset, you have to spread the character over *two* print positions — to generate two new characters, one containing the left part of the old character and the other holding the righthand part. Then you print these, side by side — et voilà!

In the present case, you can see that the letter 'B' has been shifted to the left by two bits, the letter 'C' by four bits, and the letter 'D' by six bits.

So that we have, as it were, three composite characters holding the four original letters.

We'll look at the shifting processes required to move over the characters later, but it is plain that we shall have to organise some kind of counter to deal with the number of bits shifted — two, four or six.

Organising a counter

Let's consider this counter first. Since the routine is going to be called to cope with each letter in turn, the counter will have to be kept in a 'fire-proof' location, where we can always get at it, but where it won't be lost whenever we go back to BASIC.

One address which answers this description is the 'unused' system variable location at 5C81h (23681d). We could initialise this before we start using the printing routine, and arrange for it to have 2 added to it on each pass of the routine. The routine must also recognise when it gets greater than 6 and zero the byte again.

Here is a short piece of code, which will do that:

```
            21 81 5C    LD HL,5C81
            34          INC (HL)
            34          INC (HL)
            7E          LD A,(HL)
            CB 5F       BIT 3,A
            28 02       JR  Z, Next Op.
            CB 9E       RES 3,(HL)
Next Op.
```

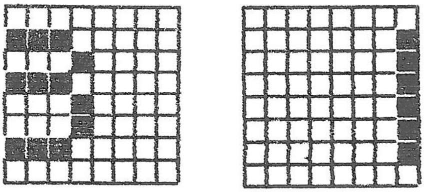
Notice how we spot that the counter has gone past '6', and how we zero it. When the routine adds 2 to a '6' in the byte addressed by HL it increases to 8, which means that it sets bit 3 for the first time and resets the lower bits in the byte. By loading A from HL and testing bit 3, we can spot when it has reached '8'. Then, by resetting bit 3 in HL, we clear the byte in the counter. We could, of course, test the bit in HL directly, but we need it in A to use it as a counter, so we might as well test it in A.

Shifting the letters

The business of getting the letters shifted into their new positions is fairly simple but laborious — like a lot of machine code.

We need three UDG characters to operate with (I have chosen UDG 1, 2 and 3 — 'A', 'B' and 'C'). Of course, in the routine we have to operate a byte at a time, but the principle shows up more clearly if we illustrate it with the complete character position of eight bytes.

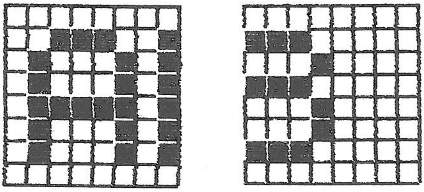
If character 'A' is the first letter in the block of four and character 'B' is the second, then we first place 'A' in UDG 1 and 'B' in UDG 2. Then we start shifting 'B' to the left, with an arithmetical shift, which places a '0' in bit '0' and pushes bit 7 off into the carry. When that has been done, we scoop up the carry with a rotate left operation and transfer it into the blank UDG 3 bytes. After this has been done twice (for the whole character position), the two characters will look like **Figure 7.3**.



UDG 2 UDG 3

Figure 7.3

Now we can OR UDG 3 with UDG 1 (byte by byte, of course) and we have our first two characters correctly spaced in UDG 1 and UDG 2, where we can print them (see **Figure 7.4**).



UDG 1 UDG 2

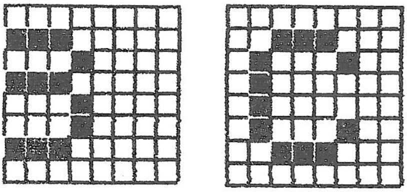
Figure 7.4

Two things remain to be done, before we can move on to the next letter in our block. First, we must backspace the print position so that it points to the place where we printed UDG 2. We shall be printing pairs of UDG 1 and UDG 2 all the time, but each time backspacing so that we pick up the former UDG 2 position.

Next, we have to get the former UDG 2 into the new UDG 1, leaving UDG 2 available for the next letter.

The beginning of the next print cycle sees the two UDGs looking like **Figure 7.5**.

Now we can shift the 'C', using the same techniques, but this time for



UDG 1 UDG 2

Figure 7.5

four bits, rather than two. When that is done, we adopt the same system to deal with 'D', making a 6-bit shift, after which our printed block will be complete and we start the cycle over again.

Here is the complete listing:

Six-bit Code Entry

```
FBA0  3A 08 5C    LD    A,(5C08)   GET ADDRESS IN NEW CHAR.-
FBA3  D6 20       SUB   20           SET FOR CHR IN LAST_K
FBA5  6F          LD    L,A
FBA6  26 00       LD    H,00
FBA8  29          ADD   HL,HL
FBA9  29          ADD   HL,HL
FBAA  29          ADD   HL,HL
FBAB  01 00 FC    LD    BC,FC00
FBAE  09          ADD   HL,BC

FBAF  11 60 FF    LD    DE,FF60  }
FBB2  01 08 00    LD    BC,0008  } LOAD NEW CHR INTO UDG 2
FBB5  ED B0       LDIR           }

FBB7  06 08       LD    B,08     }
FBB9  AF          XOR   A        }
FBBA  12          LD    (DE),A   } CLEAR UDG 3
FBBB  13          INC   DE       }
FBBC  10 FC       DJNZ  FBBA     }

FBBE  21 81 5C    LD    HL,5C81
FBC1  34          INC   (HL)       INC COUNT
FBC2  34          INC   (HL)
FBC3  7E          LD    A,(HL)
FBC4  CB 5F       BIT   3,A
FBC6  28 02       JR    Z,FBCA     CHECK? COUNT = 8
FBC8  CB 9E       RES   3,(HL)       JUMP IF SO
FBCA  21 60 FF    LD    HL,FF60
FBCD  20 22       JR    NZ,FBF1
```

```
FBCF 06 08    LD    B,08       )
FBD1 1E 68    LD    E,68       |
FBD3 F5       PUSH  AF         |
FBD4 CB 26    SLA   (HL)       |
FBD6 EB       EX     DE,HL     |
FBD7 CB 16    RL    (HL)       |
FBD9 EB       EX     DE,HL     > SHIFT CHR POSITION IN
FBDA 3D       DEC   A          |   UDG 2/3
FBDB 20 F7    JR     NZ,FBD4   |
FBDD F1       POP   AF         |
FBDE 23       INC   HL         |
FBDF 13       INC   DE         |
FBE0 10 F1    DJNZ  FBD3       )

FBE2 EB       EX     DE,HL     )
FBE3 2E 58    LD    L,58       |
FBE5 06 08    LD    B,08       |
FBE7 1A       LD    A,(DE)     |
FBE8 B6       OR    (HL)       > 'OR' UDG 1 AND UDG 3
FBE9 77       LD    (HL),A     |
FBEA 23       INC   HL         |
FBEB 13       INC   DE         |
FBEC 10 F9    DJNZ  FBE7       )

FBEE 3E 90    LD    A,90       PRINT UDG 1
FBF0 D7       RST   10
FBF1 3E 91    LD    A,91       PRINT UDG 2
FBF3 D7       RST   10
FBF4 3E 08    LD    A,08       PRINT BACKSPACE
FBF6 D7       RST   10

FBF7 1E 58    LD    E,58       TRANSFER UDG 2 TO UDG 1
FBF9 0E 08    LD    C,08
FBFB ED B0    LDIR
FBFD C9       RET
```

The actual sequence of operations within the routine, is that described a few pages back, but there is a certain amount of fancy footwork in the addressing, which perhaps needs some comment.

Saving bytes

The first thing to note is that most of the addresses deal with the three user-defined graphics, UDG 1, 2 and 3. All these have addresses beginning 'FF..'. In addition, these addresses are confined to the two registers HL and DE, where they are used to transfer our characters at various stages. This means that, once these registers have been initialised, the first byte (the byte in H and D) remains unchanged so that, instead of using the three-byte instructions 'LD HL,xxxx' and 'LD DE,xxxx', we can use the two-byte instructions 'LD L,xx' and 'LD E,xx'.

Another byte-saving operation comes at FBB7h, where we clear UDG 3, in order to make it ready to receive our new character. UDG 3 starts at FF68h, and it so happens that DE holds this address at the end of the LDIR operation in the previous section. So we don't need to re-address a register in order to do the clearing operation. Another three bytes saved.

Similarly, at the end of the shift operation DE points to UDG 3. We actually want this address in HL, for the next section, so we get it there by doing 'EX DE,HL', after which we can re-address the new DE.

Again, at FBF7h, the two registers HL and DE are unaltered by the 'RST 10' operations. HL already points to UDG 2 (after the end of the previous section), so we only have to change the E register to get both of the required addresses for the final transfer.

The way we check and zero the count is worth a glance, too, as it is a slight variation on the basic method explained. The counter number is held in 5C81h. First we increase this number by 2, and get it into A. We test bit 3 of A, to see if the number has reached 8. If bit 3 is set, the number is '8' and the zero flag will be *reset* by the 'bit' operation. If bit 3 is not set, the number has not reached 8 and the zero flag will be *set*.

This zero flag is used to control two conditional jumps, which combine to route the program in the way required.

In the first case, if the zero flag is *not* set, the first jump, at FBC6h, is skipped. The routine goes on to 'RES 3,(HL)' and 'LD HL,FF60'. Neither of these operations affects the flags, although you might think that the reset operation would do so. So the zero flag is still in control and will cause a jump to 'PRINT UDG 2', at FBF1h. When we get to the final transfer at FBF7h, HL will be ready with the right address.

In the other case, where the zero flag *has* been set (ie the count is less than 8), the roles of the two jumps are reversed. The 'JR Z' at FBC6h will cause a jump to 'LD HL,FF60' at FBCAh, skipping the reset operation. Then the 'JRNZ', at FBCDh, will be ignored and the routine will continue with the character shifting operation.

This double shuffle is needed because both sections of the routine require the same address in HL, but we can't load HL before the bit test, because it holds the address of the bit we are testing! The technique does not require any extra instruction in the program, and it saves three bytes for another 'LD HL,xxxx' instruction.

All this cheese-paring over bytes is not absolutely necessary, but the savings can mount up over a long program. In the present case, it saves about 16 bytes over a fully-addressed routine, equivalent to about 15%. The way to do this is to get the program working in the simple extended mode and then analyse it to see whether there is scope for worthwhile compression. It's unwise to try and plunge right in with the clever stuff.

Using the six-bit characters

Even though we have achieved the '40-character line', there are certain restrictions on using this technique. Although it is possible to include a new-line facility, much as we did for the four-bit routine, there isn't a really satisfactory way of doing a backspace to correct an error, because of the way the letters overlap the bytes. In fact, I cannot see much point in using this technique to produce a printout on the screen, in the typewriter mode.

The real future of the six-bit character set lies in its use for printing out labels or text. For example, if you have an address book or a telephone directory program, the entries could be printed out much more neatly and economically using the new character set. This means that you would be picking up and printing existing strings, or other data, where the lack of correction capabilities would not matter. **Figure 7.6** shows the gain in compactness.

```
This is a 32 character line ****

This is a 40 character line. in 6-BIT***
```

Figure 7.6

To access the routine from an existing string, you would need a BASIC program something like this:

Six-bit Printing — demonstration

```
 10 LET w$="This is a 40 character line
 in 6-BIT***"
 20 PRINT AT 9,0;w$
 30 POKE 23681,6
 40 FOR j=1 TO LEN w$(j): RANDOMIZE USR
64416
 60 NEXT j
```

The POKE in line 30 initialises the counter at '6'. This means that the routine will print the first letter as the start of a block of four in the position of letter 'A' in Figure 7.2.

These printing suggestions would not be of much practical use if we could not use the printer. Here again, this can be done, but you have to be slightly devious to manage it.

The trouble is that the LPRINT command, which outputs to the printer buffer, seems unable to cope with the backspacing and other peculiarities required to print our pairs of UDGs. The solution is to prepare a complete line in advance in the display file and then send it to the printer, using a modification of the COPY command.

As constituted in the ROM, the COPY routine sends the entire display to the printer, a pixel line at a time, jumping around in the display file, so as to achieve consecutive lines, in spite of the awkward arrangement of the file (see Chapter 9).

We only want to send eight lines of pixels, so the re-addressing required is minimal. We can butcher the ROM COPY routine (which starts at 0EACh) to make a simple version to pick one line off the screen and COPY it to the printer.

The line of six-bit printing has to be put on the screen somewhere, before it can be COPYed, and perhaps the most suitable place is in the lower screen, where it won't interfere with the main display. This merely involves including 'PRINT #1;' in the BASIC program given above.

The reorganised COPY routine goes like this:

PRINT Line 1 in Lower Screen

```
FF00 F3          DI
FF01 06 08       LD   B,08
FF03 21 E0 50    LD   HL,50E0  ADDR OF LINE 1 IN LOWER
                               SCREEN
FF06 E5          PUSH HL
FF07 C5          PUSH BC
FF08 CD F4 0E    CALL 0EF4     CALL PRINTER SUBROUTINE
FF0B C1          POP  BC
FF0C E1          POP  HL
FF0D 24          INC  H
FF0E 10 F6       DJNZ FF06
FF10 CD DA 0E    CALL 0EDA     FINAL SECTION OF COPY ROUTINE
FF13 06 02       LD   B,02
FF15 CD 44 0E    CALL 0E44     CLEAR LINE ROUTINE
FF18 C9          RET
```

It starts off with a 'disable interrupts' instruction, as does the original ROM COPY routine. We provide an eight-digit counter in B and load HL with the start address of the first line in the lower screen, which is 50E0h. The actual printer subroutine is at 0EF4h, which sends a single line from the screen to the printer buffer. 'INC H' re-addresses HL to the next line of display. The routine goes back to the ROM at 0EDAh, for the end section of the ROM COPY routine. This actually LPRINTs the line and finalises. The last two instructions before RET are for good housekeeping. They clear the bottom two lines of the display, ready for another bout of printing.

The routine used for this purpose is the ROM CL_LINE subroutine at OE44h. This clears the number of lines specified in B, from 1 to 24, starting at the bottom of the display. It is an extremely useful supplement to the full CLS routine at 0D6Bh.

Assuming your coding is grouped as follows, we are ready for the final BASIC program.

FBA0–FBFD	6-bit print	64416d start
FC00–FEFF	character set	
FF00–FF18	COPY	65280d start

Here is the BASIC demonstration program:

Six-bit Character Printout

```
 10 LET w$="This is a 40 character line
 in 6-BIT***"
 20 PRINT AT 9,0;w$
 30 POKE 23681,6   .
 40 FOR j=1 TO LEN w$(j): RANDOMIZE USR
64416
 60 NEXT j
 70 RANDOMIZE  USR 65280
```

If the sight of lines of text flashing on and off at the bottom of the screen as they are sent to the printer bothers you, you can add 'INK 7;' at the end of line 30.

CHAPTER 8
Sprites — Animation

Everybody has to have sprites these days: a group of bytes — usually containing a graphic image — which can be moved about the screen independently of anything else on view.

The more ambitious sorts of sprite are under the control of a special chip, which looks after the coordination of the separate bytes, so that all the programmer has to do is to indicate the direction and range of the movement. The Spectrum does not have such a chip, so all 'spritely' movements have to be done under the control of software.

There are three types of movement we shall have to consider — movement within the sprite (or animation); movement about the screen; and (what may be slightly different) movement in front of, or behind, other sprites or pieces of the background.

In this chapter, we'll deal with the first type of movement, movement within the sprite.

Drawing sprites

For any kind of animation, you need to prepare a cycle of drawings, each one differing slightly from the last, so that when the cycle is run through repeatedly it looks like movement on the screen.

It is perfectly possible to animate within a single character — the UDG characters are very handy for this kind of thing, as well as for other purposes. Here is an example — a nasty little face called Snapper which I have used in games.

DATA for snapper graphics

Face 1	*Face 2*	*Face 3*	*Face 4*
126	126	126	126
255	219	255	255
165	255	153	153
129	165	255	153
129	129	165	255
165	165	165	102
102	102	102	60
60	60	60	0

Compile Snapper Graphics

```
SNAPPERS

   5 DATA 126,255,165,129,129,165,102,60
,126,219,255,165,129,165,102,60,126,255,
153,255,165,165,102,60,126,255,153,153,2
55,102,60,0
  10 FOR j=0 TO 31
  20 READ n: POKE USR "A"+j,n
  30 NEXT j
```

This shows what the snappers look like.

Snapper

```
100>FOR j=0 TO 3
110 PRINT AT 10,10;CHR$ (144+j)
120 PAUSE 5: NEXT j
130 PAUSE 10: GO TO 100
140 REM SNAPPERS:
```

But really to expand your artistic talents, you need more than one character space — you need a sprite. Let's say a block of nine character spaces, making a 3 × 3 square.

Drawing within a 3 × 3 square has to be slightly more complicated than drawing within one character. There are a number of drawing programs available, but here is a simple one which I have set up to produce the kind of thing we want.

Draw a Sprite

```
   5 LET n=1: LET a=0
  10 LET x=12: LET y=163
  15 PRINT AT 0,(x-12)/8; PAPER 5;" "; P
APER 6;" "; PAPER 5;" "
  16 PRINT AT 1,(x-12)/8; PAPER 6;" "; P
APER 5;" "; PAPER 6;" "
  17 PRINT AT 2,(x-12)/8; PAPER 5;" "; P
APER 6;" "; PAPER 5;" "
  20 PLOT INVERSE a;x,y
  25 PRINT AT 18,0;"Draw frame No. ";n'"
3=</ 4=<\ 9=>/ 0=>\"
  30 PAUSE 0
  40 LET y$=INKEY$
  45 IF y$="z" THEN LET a=NOT a
```

```
  50 IF y$="5" THEN LET x=x-(x>0)
  51 IF y$="8" THEN LET x=x+(x<23)
  52 IF y$="6" THEN LET y=y-(y>152)
  53 IF y$="7" THEN LET y=y+(y<175)
  54 IF y$="9" THEN LET x=x+(x<23): LET
y=y+(y<175)
  55 IF y$="0" THEN LET x=x+(x<23): LET
y=y-(y>152)
  56 IF y$="4" THEN LET x=x-(x>0): LET y
=y+(y<175)
  57 IF y$="3" THEN LET x=x-(x>0): LET y
=y-(y>152)
  58 IF y$=CHR$ 13 THEN GO TO 100
  60 GO TO 20
```

When the program is run, the cursors will print a line, a pixel at a time, right, left, up and down. Keys '3', '4', '9' and '0' make the diagonal lines, as shown.

Lines 15, 16 and 17 print a check in pale blue and yellow, which helps you to find your whereabouts when plotting. The (x > 0), (y < 175), etc., is to stop the dots running off the square. These expressions are worth 1 if they are true or 0 if they are not true; so they will only change the values of x or y if either x or y are within the defined limits. In line 58, '13' is the code for ENTER, which ends this part of the program.

Keying 'z' INVERTs the PLOT command (line 45). This means that operating the cursors *rubs out* the pixels already written. This goes on until you press 'z' again.

Now you can draw your sprite. It's a help, sometimes, to have it sketched out in advance on a scrap pad. Once you have completed your sprite to your satisfaction, the next thing to do is to arrange to store it somewhere. At the moment, it only has a precarious life in the display file and on the screen.

Here is a program to store your sprite, byte by byte, in the upper RAM, starting at address 61440d. There is nothing magic about this address, but it has the convenience of being F000h, which means that the LSB (least significant byte) is zero. Since you will want to add to this number, it helps to start at the bottom of the ladder.

Store Sprite in Upper RAM

```
  5 LET n=1: LET a=0: LET q=61440
100 FOR k=0 TO 2
110 FOR i=0 TO 2
120 FOR j=0 TO 7
```

```
130 POKE q+j+8*(i+3*k),PEEK (16384+32*k
+256*j+1)
140 NEXT j: NEXT i: NEXT k
150 LET q=q+72
160 LET n=n+1: IF n<5 THEN GO TO 20
```

The program is very short, but it brings in four new variables, which work like this. The start address of each sprite group is pointed to by 'q', which is increased by 72 on each pass (line 150). The loops controlled by 'k', 'i' and 'j' select each byte in the group in order — 'j' picks the eight bytes in the character space, 'i' picks the column position and 'k' the line position.

The '256' tied to 'j' in line 130 is the result of the way in which the display file is organised in the Spectrum (see the next chapter). All the first bytes of the top eight lines of the display are scanned first, then the second bytes, and so on (see p.164 of the Spectrum manual). This may answer a deep-felt need in the Spectrum ROM, but it can make life a misery for programmers, especially in machine code. You are always having to add 256 and remember if you are in line 8 or 9.

The variable 'n' just controls the number of sprites we are generating. I have picked four. Three is the absolute minimum for a reasonable animation cycle, but four makes it much smoother.

Enter this program and MERGE it with the previous one. When you come to RUN it, you will get a chance to design and store four sprites. The second part of the program, which stores the sprites, takes a little time to execute — wait for the next number to appear before using the cursor again.

In this program, the current cursor position and the previous pattern are preserved. Most animation consists of *modifying* a design, leaving some of it unchanged: you can do this by using the 'rub-out'.

If you want to have a blank screen each time, change line 165 to 'GOTO 10'.

A routine to view the finished graphics is quite easy to devise and will fit comfortably into most programs. The trick is to change the system variable UDG at 5C7Bh (23675d), so that it points to the start of each of the sprites in turn. The respective characters will then appear in the UDG positions, 'A,B,C,D,E,F,G,H,I'.

Now you can appreciate the advantage of having a start address at F000h. Each sprite begins 72d bytes on from the last, which corresponds to 48h. So the LSBs of the start addresses become 0, 72, 144 and 216 (00, 48, 90 and D8 in hex). These are all less than 256, so you do not have to alter the MSB.

Here is a demonstration program in BASIC, which will do all this: 'ad1' is the LSB of the address we have been talking about and 'ad2' is the MSB.

Display Animation

```
170 PRINT AT 20,0;"Any key shows animat
ed sequence": PAUSE 0
180 CLS
190 PRINT AT 20,0;"""O"" aborts"
200 LET ad1=0: LET ad2=240
210 FOR j=0 TO 3
220 POKE 23675,ad1: POKE 23676,ad2
230 PRINT AT 10,14;"ABC";AT 11,14;"DEF"
;AT 12,14;"GHI"
240 PAUSE 5: LET ad1=ad1+72
250 IF INKEY$="O" THEN STOP
260 NEXT j
270 GO TO 200
```

This program has been laid out in the form of a loop, controlled by 'j'. However, when used in an actual program — a game, or something like that — you might want to 'POKE ad1' with the appropriate values and print out the sprite at four separate points of your program, so as to distribute the printing evenly through the main loop of your game. In that case, of course, you would drop the 'PAUSE 5' shown in line 240 — a game program would probably supply more than enough delay!

You can obviously print the block of characters anywhere you like and you can easily arrange for the print position to move about under a player's control.

To illustrate what you can do, I have drawn out a little animated cycle of a matchstick man running (**Figure 8.1**). I have done it on squared paper, where each square in the graph corresponds to eight bytes, or one character (see next chapter).

Note that the man's body moves forward four pixels (quarter print position) each frame — this means that at the end of the cycle he is ready to start again with the whole sprite moved forward one print position. Obviously, the foot on the ground stays in the same position, but the other foot moves forward through the cycle to come down in the corresponding position, when the sprite moves forward.

If you draw this action for yourself and incorporate it in a BASIC program with a FOR...NEXT loop, which moves the print position one place to the left each time round, you'll be surprised how lifelike it turns out to be. Don't be put off if the drawings are not dead accurate and you

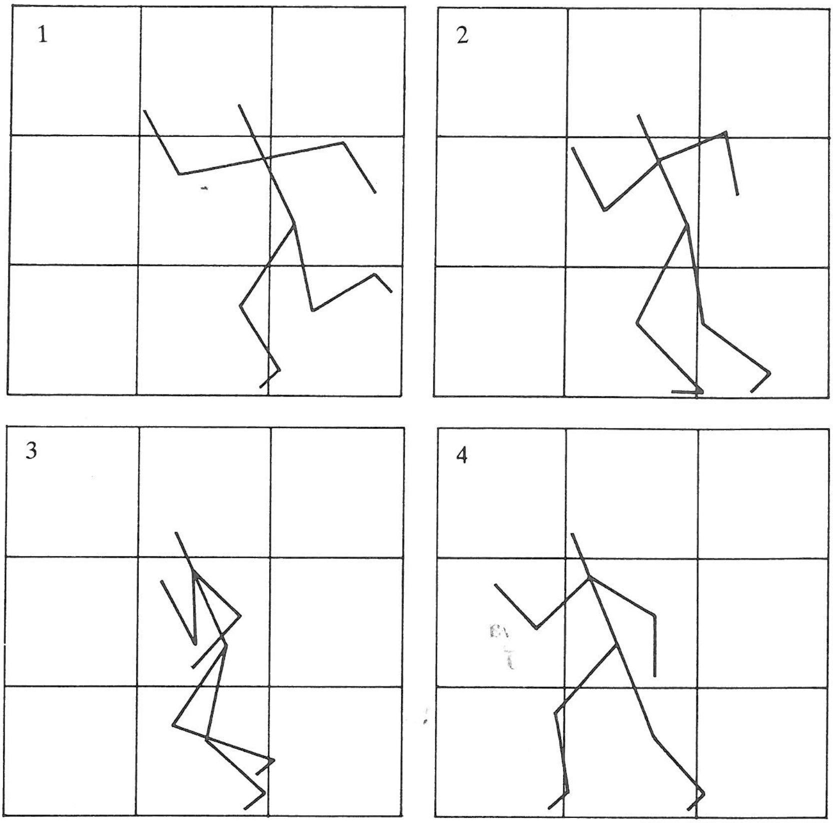


Figure 8.1

make some mistakes. It doesn't seem to show when in action — the odd wiggle often gives it an extra touch of character!

CHAPTER 9

The Moving Sprite

When using animation within a sprite you can generally do most of the programming in BASIC. Using the print position as a unit of movement is usually perfectly satisfactory (as in the running man example in the previous chapter).

However, when it comes to moving a sprite bodily about the screen, things are rather different. What makes a first-class moving sprite so appealing is that it moves smoothly, one pixel at a time.

Display file layout

Using BASIC, there is no w y that you can print to screen in other than the normal print position. But, to move a sprite, we want to be able to print it starting on *any* line of pixels, and at any column of pixels. This means that we have to abandon the Spectrum's programmed print instruction and shoot the bytes directly into the display file.

In itself, this is not very difficult.

I have read many descriptions of the layout of the Spectrum display file, but I still find it hard to visualise. Here is a variation, which I have found as helpful as any.

Think of the display as being in three immensely long lines, each of 256 characters. These will eventually form the three horizontal thirds of the TV screen. Each of the long lines begins at a separate display file address: 4000h, 4800h and 5600h.

Every character in the long line is made up of eight bytes — eight pixel lines — and each of the long lines is stored in the display file, one after the other. So a character in position 3 (as in **Figure 9.1**) will be formed from a byte from address 0 + 3, with below it a byte from address 256 + 3; then a byte from 512 + 3, and so on.

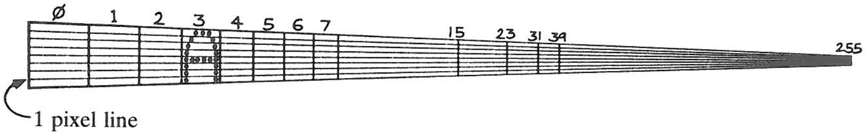


Figure 9.1: One of the Three Imaginary 255-Character Lines

(You may have spotted that the address of each of these bytes takes the form of 'x003', 'x103', 'x203', etc. In fact, to address all the eight bytes which make up a character with its address in HL, we do 'INC H' eight times, to get the eight addresses.)

The actual Spectrum screen is, of course, 32 characters wide. To make the screen, each of the long character lines (eight pixels thick) is 'cut up' to make eight screen lines, each of 32 characters (**Figure 9.2**). But the addressing of bytes on the screen remains the same as it was in the original 256-character lines.

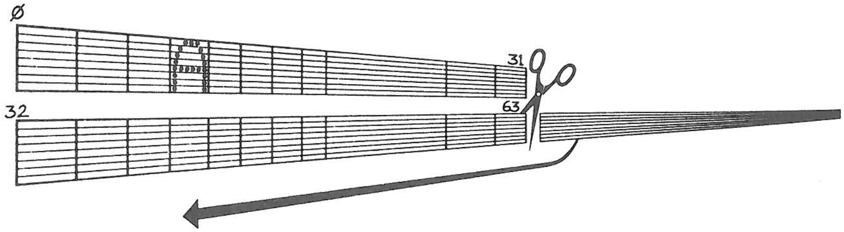


Figure 9.2: The Character Line is 'Cut up' into 8 32-Character Lines

You can see that, in normal printing, finding the address of a character and printing each of its bytes in the right position can be done quite neatly.

But suppose that we don't want to start printing on a pixel line 0—what will happen then? If we want to place the first byte of our character on pixel line 4, say, what do we do about the positions of the other bytes?

The first four bytes go into place easily enough, using the system outlined above. But then we get to the bottom of our long character line, and we still have four bytes in hand. Where do they go? There must be *something* under this print position (unless it is the very bottom of the screen) but what can it be?

The answer is that, because of the 'cutting up' of the long lines, the next print position is at the *top* (pixel line 0) of the same long character line, but 20h (32d) characters long (see **Figure 9.3**)! So if, for example, we are dealing with an address in DE, we would take away 700h (to get back to pixel line 0), decrementing D, and add 20h to E.

If we want to cross over from one long line to the next, we have to add 0800h (2048d) to the base address.

As you can imagine, writing a program to do all this — and then augmenting it to deal with a sprite of nine characters — with loops within loops within loops all needing to be kept track of, has the registers PUSHing and POPping like a bowl of breakfast cereal!

But cheer up! Rescue is at hand! Sinclair Research have done all the work and have included their elegant result in the Spectrum ROM. There

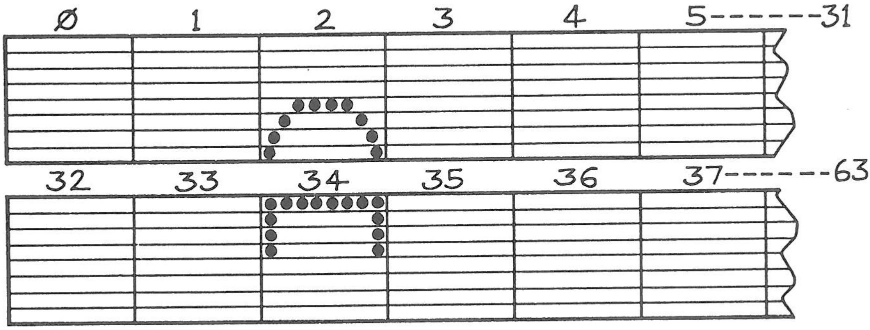


Figure 9.3: Printing a Character across Two Different Character Squares

is a subroutine at 22AAh, called PIXEL__AD, which does everything we could ask for.

This routine is used when executing PLOT and finding POINT. We take the x and y coordinates of a pixel position and put them into the BC register pair. Then we call PIXEL__AD, and back comes the address in HL to which the byte must be loaded, so as to get it into the display file at the correct position. Better than that, the A register contains a number which indicates the position *within* that byte of the pixel we have addressed.

So HL contains the exact pixel line (the y coordinate) plus the x axis print position (the 'coarse' x coordinate), while A contains the exact pixel position (the 'fine' x coordinate).

(Before we go on to see how we can use these goodies in practice, you may be interested to take the figures we've been dealing with a little further. Each of the long character lines we started with contains 256 characters, each made up of eight bytes. As each byte contains eight pixels, this means that each of our character lines contains 256 × 8 × 8 = 16,384 pixels. As the screen is made up of three of these character lines, this gives us 3 × 16,384 = 49,152 pixels on the Spectrum display screen, every one of which can be individually addressed.)

Printing a vertically offset character

Let's deal with the simplest case first. Suppose we print a single character to the screen, using a routine which selects any pixel line (y coordinate) we choose.

The principle is to get the coordinates of the top lefthand corner of the character into BC, CALL PIXEL__AD and load the first byte of the character into the address held by HL. We then move to the next byte of the character, *decrease* the y coordinate by one (the y coordinates are read from the *bottom* of the screen to the *top*) and call PIXEL__AD again, before printing the next byte. And so on, through all eight bytes of the character.

Obviously, this is a case for a control loop, to count the eight bytes, and the neatest loop is the one operated by DJNZ. This requires a control number in B, but we already have to use BC for the pixel address. We can't easily store the register with a PUSH, because we really need to *exchange* the registers for use at different points. So that is what we shall do — we'll use the alternate registers and access BC′.

Here's the program.

Print 'A' at Pixel Coordinates 88,172

61440

```
F000 01 58 AC      LD    BC,AC58      COORDINATES
F003 ED 5B 7B 5C   LD    DE,(5C7B)    ADDRESS OF UDG IN
                                       SYST. VARS
F007 D9            EXX
F008 06 08         LD    B,08         BYTE COUNT
F00A D9            EXX
F00B C5            PUSH  BC
F00C CD AA 22      CALL  22AA         CALL PIXEL_AD
F00F 1A            LD    A,(DE)
F010 77            LD    (HL),A
F011 13            INC   DE
F012 C1            POP   BC
F013 05            DEC   B
F014 D9            EXX
F015 10 F3         DJNZ  F00A
F017 D9            EXX
F018 C9            RET
```

Notice that BC prime holds AC58 at the start — this is hex for 172, 88. Also, at line F003h we have, once again, pointed DE to the address for UDG in the system variables, at 5C7Bh, so that if you wanted to re-address the graphics to another address by altering UDG, the routine would still work. This could be useful for animation.

Here is a BASIC (very basic) program to demonstrate the routine:

Off-line Printing — demonstration

```
  10 PRINT "XXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXX"
  20 RANDOMIZE USR 61440

XXXXXXXXXXXAXXXXXXXXXXXXXXXXXXXX
```

The line of Xs gives a reference line and you can see how the graphic 'A' has been offset downwards.

Printing a horizontally offset character

The next thing to consider is how to offset the graphic character to one side. So far, we have only accomplished an up-and-down movement. We have to tackle this in a rather different way.

As I pointed out in Chapter 7, there is no way, on the Spectrum, that you can directly print a character offset to the left or right, as the print positions are laid down hard and fast.

To print a character which is laterally offset, we have to spread the character over *two* print positions.

As before we shall need to use the carry — literally to carry the bits spilled off the end of one byte, as we move it over, into the adjacent byte of the second character.

Each rotation will move the character over one bit (one *pixel*) so, to take up our chosen position, we shall need to use the number left in A after CALL PIXEL__AD (the exact pixel position) to control the number of rotations.

Here is the coding.

Shift Character to Right by Number in A

```
F020 01 AC 5B      LD    BC,5BAC   CO-ORDS.
F023 CD AA 22      CALL  22AA      CALL PIXEL__AD
F026 4F            LD    C,A       NO OF DISPLACEMENTS INTO "C"

F027 A7            AND   A
F028 C8            RET    Z        CHECK FOR ZERO SHIFT

F029 21 58 FF      LD    HL,FF58   UDG "A"
F02C 11 60 FF      LD    DE,FF60   UDG "B"
F02F 06 08         LD    B,08      BYTE COUNT

F031 7E            LD    A,(HL)
F032 1F            RRA             ROTATE 1st CHR
F033 77            LD    (HL),A
F034 1A            LD    A,(DE)
F035 1F            RRA             ROTATE 2nd CHR
F036 12            LD    (DE),A
F037 23            INC   HL
F038 13            INC   DE
F039 10 F6         DJNZ  F031
```

```
F03B OD         DEC  C
F03C 20 EB      JR    NZ,F029
F03E C9         RET
```

You can see that, after supplying the start address in BC, we call PIXEL_AD at once and get the magic number from A into C. We have lost interest in the start address for the present, so we can afford to re-use BC for this new purpose. We are also not interested in the new address supplied in HL, so we use HL and DE for the addresses of the first two user-defined graphics, 'A' and 'B': the 48K Spectrum places these at FF58h and FF60h.

The two instructions 'AND A' and 'RET Z' are safety nets. ('AND A' tests to see whether A is zero: if it is, we don't need to do any rotation, so we jump out of the subroutine. If this test were not there, the subroutine would cycle through 256 times!)

The inner loop, controlled by B, does the rotation for each pair of bytes in the characters in turn. The outer loop, controlled by C, repeats this operation the required number of times (in this case, four).

Before running the demonstration program, you should make UDG 'B' a blank, by POKEing 0 to all eight bytes. Then try this:

Off-column Printing — demonstration

```
  10 PRINT "XXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXX"
  20 RANDOMIZE USR 61472
  30 PRINT AT 1,10;"AB"
  40 PRINT AT 2,10;"A B"
```

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
          A
```

You can see that UDG 'A' appears to have been printed in a position midway between the Xs. In fact, it is not one, but *two* characters, as you can plainly see in the third line of the printout, where there is a gap between the two halves.

Printing a sprite

Armed with the results of these experiments, we are now ready to tackle the case of the sliding sprite. But before we start scaling up the routines, there is a bit of preparatory work to do on the sprite itself.

In the first place, we shall have to make it *four* bytes wide, rather than three, even though the graphics will remain 3 × 3. This is to allow for the extra byte to take up the slack in a horizontal move, as in the previous routine.

Secondly, life is much easier if we rearrange the bytes of the sprite, so that we can have all the bytes for each horizontal row side by side — rather, in fact, as Sinclair have arranged the display file in the Spectrum! **Figure 9.4** illustrates what I mean. This shows the way in which the graphics are arranged at the top of the RAM.

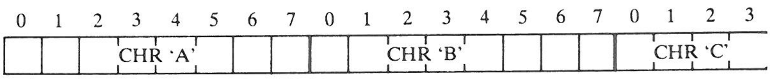


Figure 9.4

We shall rearrange them as in **Figure 9.5**.

A0	B0	C0	0	A1	B1	C1	0	A2	B2	C2	0	A3	B3	C3	0	A4	B4	C4	0

Figure 9.5

This manoeuvre means that we can load the bytes into the display file in one easy movement, rather than hop eight bytes for every operation. Better still, we can do the rotate operations by running down the complete line (like a zip fastener!).

The shuffling routine is quite simple, though there has to be a bit of a hiccup after every eighth move, when we have completed one set of three characters and have to move on to the next set.

You have to choose an address to which to copy this new arrangement —another scratch-pad — and, once again, I suggest using the printer buffer, just below the system variables. It will be free when we need it, it is fixed and unaffected by the Microdrive, etc., it saves a bit of spare RAM, and it leaves the UDGs unchanged.

Rearrange First Nine UDG in PR_BUFF

61696

```
F100 21 00 5B     LD    HL,5B00      PRINTER BUFFER
F103 E5           PUSH  HL           SAVE ADDRESS
F104 AF           XOR   A          }
F105 47           LD    B,A        }
F106 77           LD    (HL),A     } CLEAR PRINTER BUFFER
F107 23           INC   HL         }
F108 10 FC        DJNZ  F106       }
```

```
F10A D1          POP  DE
F10B 2A 7B 5C    LD   HL,(5C7B)   RESTORE ADDRESS
                                  UDG ADDRESS
F10E 06 03 (06)  LD   B,03        3 × GROUPS OF CHRS
F110 C5          PUSH BC
F111 0E 08       LD   C,08        8 × BYTES PER CHR
F113 06 03       LD   B,03        3 × CONSECUTIVE CHRS
F115 E5          PUSH HL

F116 7E          LD   A,(HL)   ⎫
F117 12          LD   (DE),A   ⎪
F118 C5          PUSH BC       ⎪
F119 01 08 00    LD   BC,0008  ⎬ BYTES LOOP
F11C 09          ADD  HL,BC    ⎪
F11D C1          POP  BC       ⎪
F11E 13          INC  DE       ⎪
F11F 10 F5       DJNZ F116     ⎭
F121 13          INC  DE
F122 E1          POP  HL
F123 23          INC  HL          SELECT NEXT CHR
F124 0D          DEC  C
F125 20 EC       JR   NZ,F113     CONSECUTIVE CHRS LOOP
F127 0E 10       LD   C,10        ('B' IS ALREADY 0)
F129 09          ADD  HL,BC       SELECT NEXT GROUP
F12A C1          POP  BC
F12B 10 E3       DJNZ F110        GROUP LOOP.
F12D C9          RET
```

The routine starts by clearing the printer buffer (by printing 0 throughout) — we want to have a clean scratch-pad. Then it sets up the three loops, of three, eight and three, and executes them, incrementing the source address and the destination address each time and adding 16d to the source address when it has finished one set of three characters. (It adds 16d, because it is already at position 8 — the end of the character —so that it only needs to hop over two complete characters to get to the start of the fourth.)

Here is a printout of the first 64 bytes in the printer buffer, after this operation. The values of the bytes are not important but you can see clearly how they have been arranged in groups of four, with a blank at the end.

```
5B00 00 00 00 00 3C 7C 3C 00
5B08 42 42 42 00 42 7C 40 00
5B10 7E 42 40 00 42 42 42 00
```

```
5B18 42 7C 3C 00 00 00 00 00
5B20 00 00 00 00 78 7E 7E 00
5B28 44 40 40 00 42 7C 7C 00
5B30 42 40 40 00 44 40 40 00
5B38 78 7E 40 00 00 00 00 00
```

After these preliminaries, the next move is to rotate the bytes on our scratch-pad, so as to shift the characters into the position we want. Continuing with our listing, it looks like this:

Shift Sprite to the Right by Number in A

```
F12D 01 AC 5B     LD    BC,5BAC     PIXEL COORDINATES
F130 C5           PUSH  BC          SAVE
F131 11 00 5B     LD    DE,5B00     PR_BUFF ADDRESS
F134 CD AA 22     CALL  22AA
F137 4F           LD    C,A
F138 A7           AND   A
F139 28 0D        JR       Z,F148   SKIP IF COUNT = 0
F13B D5           PUSH  DE
F13C 06 60 (C0)   LD    B,60      }
F13E 1A           LD    A,(DE)    }
F13F 1F           RRA             } ROTATE WHOLE PR_BUFF CHRS
F140 12           LD     (DE),A   }
F141 13           INC   DE        }
F142 10 FA        DJNZ  F13E      }
F144 D1           POP   DE
F145 0D           DEC   C
F146 20 F3        JR      NZ,F13B   REPEAT OPERATION
F148 C1           POP   BC          RESTORE COORDINATES
F149 C9           RET
```

You will appreciate that the listing is very similar to the Shift Character to Right listing given earlier in this chapter. If anything, it is rather simpler, as the character bytes have been rearranged in a more accessible order.

When the entire program is run, the same section of scratch-pad will look like this:

```
5B00 00 00 00 00 03 C7 C3 C0
5B08 04 24 24 20 04 27 C4 00
5B10 07 E4 24 00 04 24 24 20
5B18 04 27 C3 C0 00 00 00 00
5B20 00 00 00 00 07 87 E7 E0
5B28 04 44 04 00 04 27 C7 C0
```

```
5B30  04  24  04  00  04  44  04  00
5B38  07  87  E4  00  00  00  00  00
```

Because our chosen coordinates (which were put into BC at address F12Dh) involve a shift of four pixel positions, you will see that the same hex numerals now appear neatly shifted into the next nibble.

The next thing to arrange is for the shifted sprite to be inserted into the display file, so that it appears on the horizontal pixel line we have specified.

The routine is, again, very similar to the Shift Character to Right listing.

Print Sprite to Screen

```
F149  DD  21  00  5B  LD     IX,5B00    PR_BUFF CHRS

F14D  D9              EXX
F14E  06  18          LD     B,18       COUNT FOR 3 × 8 PIXEL LINES
F150  D9              EXX

F151  C5              PUSH   BC
F152  CD  AA  22      CALL   22AA       PIXEL_AD
F155  06  04          LD     B,04       COUNT FOR SPRITE WIDTH

F157  DD  7E  00      LD     A,(IX)
F15A  77              LD     (HL),A
F15B  23              INC    HL
F15C  DD  23          INC    IX
F15E  10  F7          DJNZ   F157

F160  C1              POP    BC
F161  05              DEC    B
F162  D9              EXX
F163  10  EB          DJNZ   F150

F165  D9              EXX
F166  C9              RET
```

You may notice that I have used the IX register to hold the scratch-pad address, rather than the obvious DE. This is because the indexing capability is going to be needed later (see Generating Hybrid Characters routine in Chapter 10).

In the meantime, if you set up a BASIC program like this:

Moving Sprite

```
10 FOR j=0 TO 50
```

```
20 POKE 61742,64+j: POKE 61743,64+j
30 RANDOMIZE USR 61696
40 NEXT j
```

you can send your sprite sailing about the screen, like a cloud in the sky. In fact, if you like to draw a cloud and get it into the UDG characters, as I have described, you can do exactly that.

CHAPTER 10
Sprite Backgrounds

If you have been pushing your sprite about the screen, you may have spotted the drawback to the routines as we have developed them so far. If there is any other printing on the screen, it is obliterated by the sprite, which always appears on a white rectangle (**Figure 10.1**).

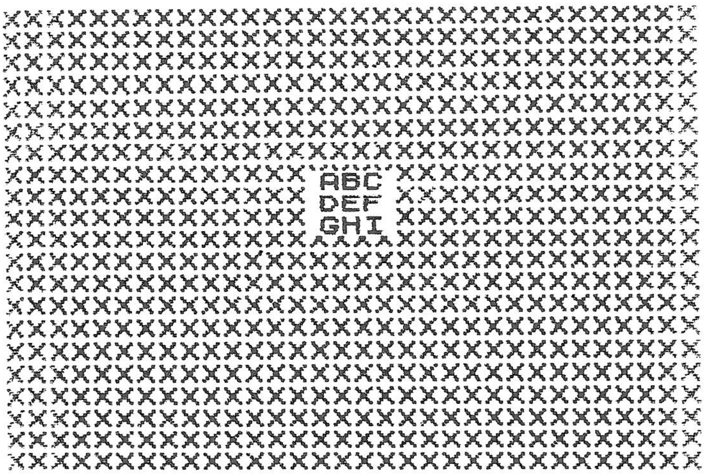


Figure 10.1

Moreover, if you move the sprite about it has a kind of hoovering action — it simply wipes out the background in its way (**Figure 10.2**).

Protecting the background

It is not too difficult to restore the wiped-out background, as the sprite moves. You store a replica of the display file containing your background in a convenient part of the RAM and call it back each time you print the sprite in a new position. This 'screen dumping' technique is another extremely useful piece of machine code, which can be used for a number of purposes, though it means sacrificing a sizeable piece of RAM to hold the replica display file.

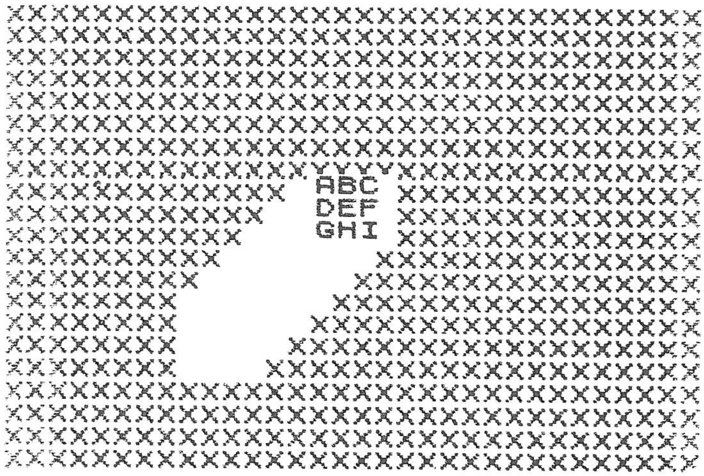


Figure 10.2

The coding could hardly be simpler: it is a straightforward LDIR operation.

Screen Dump

```
F000  21 00 40     LD    HL,4000
F003  11 00 D0     LD    DE,D000
F006  01 00 1B     LD    BC,1B00
F009  ED B0        LDIR
F00B  C9           RET
```

This stores the display file at addresses D000h to EAFFh. To call it back on to the screen needs a little more of the same:

Screen Dump — restore

```
F010  21 00 D0     LD    HL,D000
F013  11 00 40     LD    DE,4000
F016  01 00 1B     LD    BC,1B00
F019  ED B0        LDIR
F01B  C9           RET
```

The dumping/restoring routines operate so fast that they are almost instantaneous. In fact, you can use them to 'blink' on and off a line of text, or a design — simply saving the background by dumping it and then alternately printing the text and restoring the screen.

Free-floating sprites

But this still leaves the sprite on its white rectangle. Instead of having a spaceship zooming about the screen, you have a postage stamp of a spaceship, which is somehow less appealing.

In order to get the sprite floating free against any background, you have to find a way of printing that background right up to the edge of the sprite, no matter what shape your sprite is or where it is placed on the rectangle which carries it.

It is not as difficult as it might sound. In fact, we use a technique which is at least as old as the movie industry — and that is about 80 years old.

Let me tell you about the first motion picture Box Office Smash. It was made in 1903 and is called 'The Great Train Robbery'. It runs for eleven minutes. The story is simple: there's this train with a lot of bullion on it, these robbers jump into the van where it is being held, while the train is on the move, and they rob it. The big scene comes when you see the robbers overpower the guard and make off with the loot, while you can see the countryside flashing by through the open door of the van.

The point I want to make is that there was no countryside when this was filmed — the door was filled with a blank of black cardboard. Then the film was re-exposed from a moving train through another piece of black cardboard, with a hole cut in it, exactly matching the blank door in the studio set of the van. This was the invention of the matte shot!

The technique (or one much like it) is still used today on television, where it is called 'Chromakey'. It is much favoured on news bulletins, where readers can appear against a background of starving children or exploding bombs, while they are still sitting at their desks. You can usually spot the use of it by the fact that a fuzzy line appears round the foreground figures, as though drawn with a blue felt-tip pen.

To achieve a matte process by any technique requires four basic elements. They are shown in **Figure 10.3**.

A and C are the background and the foreground. B is called the 'positive matte' and D is called the 'negative matte'.

To make the composite picture, A and B are first combined, using B to mask off (or matte out) the space for the foreground. Then C is inserted into the blank space, using the negative matte, D, to mask the background area (**Figure 10.4**).

In movies, this is done by physically combining the pieces of film in an optical printer, but, to get the same effect on a computer, we can use the logical instructions in the central processor to mask out bits as required, and add others in their place.

Here is a routine to generate a 'hybrid' character in the user-defined graphics. It takes the first UDG characters, 'A' and 'B', uses a matte set

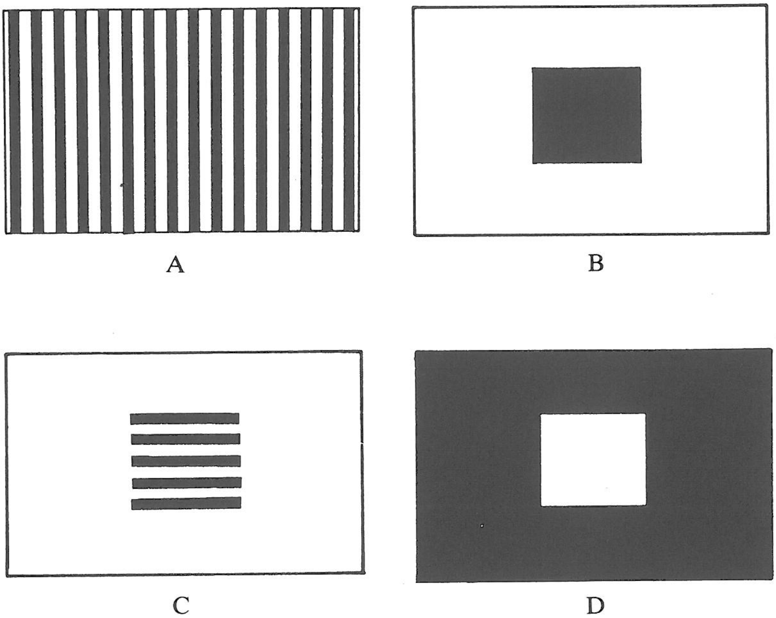


Figure 10.3: Four Elements of Matte Process

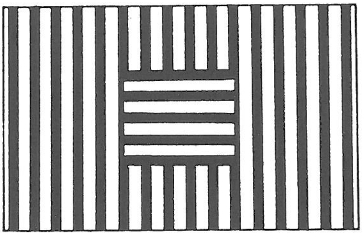


Figure 10.4: Composite Picture

up in 'C' (actually, the same as CHR$ 133, the fifth graphics character) and puts the finished hybrid into UDG 'D'.

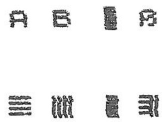
Generate Hybrid Characters

53248

```
D000 DD 2A 7B 5C LD    IX,(5C7B)  UDG ADDRESS IN SYST. VARS.
D004 06 08       LD    B,08
D006 DD 7E 10    LD    A,(IX+10)  CHARACTER 'C'
D009 2F          CPL
D00A DD A6 00    AND   (IX)       CHARACTER 'A'
```

```
D00D 4F          LD    C,A
D00E DD 7E 10    LD    A,(IX+10)    CHARACTER 'C'
D011 DD A6 08    AND   (IX+08)      CHARACTER 'B'
D014 B1          OR    C
D015 DD 77 18    LD    (IX+18),A    CHARACTER 'D'
D018 DD 23       INC   IX           INCREMENT BASE
                                      ADDRESS
D01A 10 EA       DJNZ  D006
D01C C9          RET
```

```
  10 LET n=0
  20 FOR j=0 TO 7: POKE USR "C"+
j,15: NEXT j
  30 RANDOMIZE USR 53248
  40 PRINT TAB 10;"A B C D"
```



In the BASIC program to demonstrate this, line 20 generates the matte. The combined character shows up more plainly in the second printout, where striped characters have been substituted for UDG 'A' and 'B'.

It's worth analysing how the routine works. D000h gets the starting address of UDG into the IX register. D004h sets a loop control of eight, corresponding to the eight bytes per character we have to deal with. D006h loads the A register with the first byte from the third character, the matte. The next instruction makes the *negative* matte; CPL will invert all the bits of the byte held in A. D00Ah blots out half the bits in UDG 'A' by ANDing the two bytes. D00Dh stores the result in the C register. D00Eh collects the matte for a second time and, in D012h, uses it as a *positive* matte to mask off the opposite half of UDG 'B', at IX + 10. D014h combines the two halves by ORing them and D015h loads the new byte into UDG 'D'. Then we move the address in IX up one byte and go back to do the same thing seven more times.

You can see from this routine the advantage of being able to use the indexed register IX. It allows you to address the same relative positions of all the four elements we are handling, as the program moves through the eight bytes, and you only have to increment the base address.

We shall use the same technique in addressing the sprite and its matte.

Printing sprites on the background

Expanding the routine to deal with the block of 12 bytes means just the minimum juggling with loops. To ensure that we always have access to a 'clean' background — one without sprite images already printed on it —

we make a copy, before running the routine, of the complete display file at a new address in the RAM. We use this copy as the source of the background for the composite sprite. The copying can be done with the screen dump routine, which I have placed at F180h. This loads the display file copy to a block of 1800h bytes, starting at D800h and ending one byte before F000h.

We can always find the address in the copy file corresponding to the sprite address in the actual display file, by adding a constant offset of 9800h to the display file address. This offset is placed in DE in the first instruction below:

Print Sprite with Background

```
F149 11 00 98     LD    DE,9800      OFFSET FOR D/FILE COPY
F14C DD 21 00 5B  LD    IX,5B00      SCRATCH-PAD

F150 D9           EXX
F151 06 18        LD    B,18
F153 D9           EXX

F154 C5           PUSH  BC
F155 CD AA 22     CALL  22AA         CALL PIXEL__AD
F158 06 04        LD    B,04
F15A E5           PUSH  HL
F15B 19           ADD   HL,DE        GET D/FILE COPY ADDRESS
F15C DD 7E 60     LD    A,(IX+60)    MATTE TO 'A'
F15F 2F           CPL                MAKE NEGATIVE MATTE
F160 A6           AND   (HL)         MASK BACKGROUND
F161 4F           LD    C,A
F162 DD 7E 60     LD    A,(IX+60)    MATTE TO 'A'
F165 DD A6 00     AND   (IX)         MASK SPRITE
F168 B1           OR    C            MAKE COMPOSITE
F169 E1           POP   HL           GET ORIGINAL D/FILE ADDRESS
F16A 77           LD    (HL),A
F16B 23           INC   HL
F16C DD 23        INC   IX
F16E 10 EA        DJNZ  F15A

F170 C1           POP   BC
F171 05           DEC   B

F172 D9           EXX
F173 10 DE        DJNZ  F153
F175 D9           EXX
F176 C9           RET
```

Dump D/File to D800h (51200d)

```
F180 21 00 40     LD    HL,4000
```

61824

```
F183 11 00 D8       LD     DE,D800
F186 01 00 18       LD     BC,1800
F189 ED B0          LDIR
F18B C9             RET
```

You may be wondering what an offest of 'IX + 60' is doing in the routine above. This is, in fact, the address of the matte. UDG characters ABCDEFGHI form the sprite and I have allocated JKLMNOPQR for the matte. Each group uses 60h (96d) bytes. This means two small alterations to the earlier routines we have developed:

F10E LD B,03 06 03 becomes LD B,06 06 06 (p.75)

and

F13C LD B,60 06 60 becomes LD B,C0 06 C0 (p.77)

Both numbers are doubled.

Putting it all together, here is a test program and result (in **Figure 10.5**).

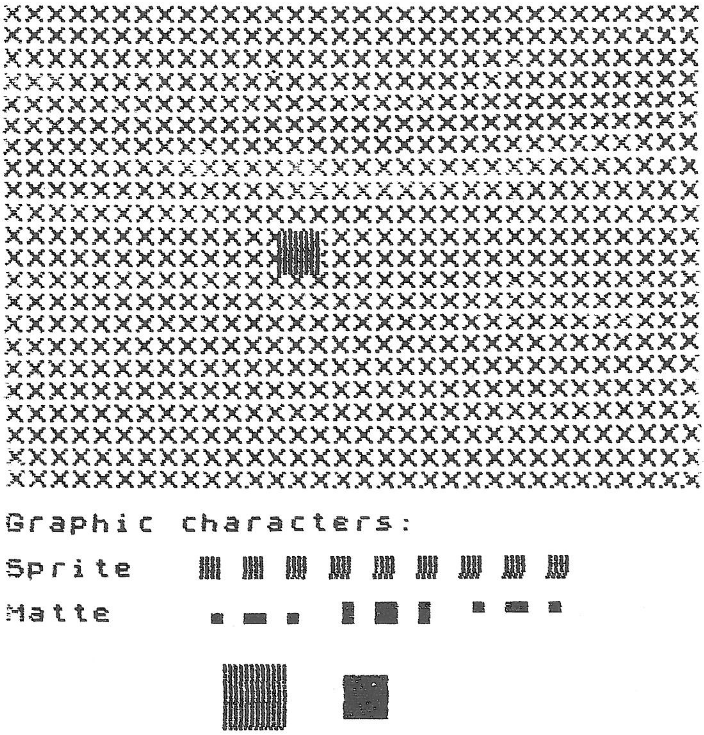


Figure 10.5

Matted Sprite — demonstration

```
  10 FOR j=0 TO 703: PRINT "X";:
 NEXT j
  20 RANDOMIZE USR 61824
  30 POKE 61742,97: POKE 61743,9
7
  40 RANDOMIZE USR 61696
```

And, of course, your sprite need not be solid, Making the central square of the matte a blank, gives the result in **Figure 10.6**.

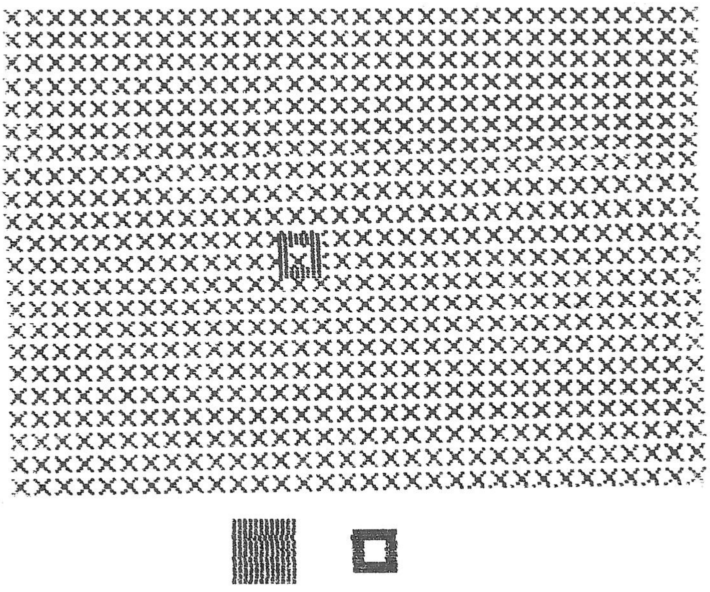


Figure 10.6

Even this by no means exhausts the possibilities of your sprite. By copying all the routines into two different locations and allocating another block of RAM as a second display file copy, you can have *two* sprites on the go.

If you use a copy of the display file with sprite 1 *already printed on it* as the 'clear' background for sprite 2, sprite 2 can be made to pass in front of sprite 1, and vice versa.

You can do a lot more with mattes. By making a matte of a section of background (perhaps using the PaintCODE routine in Appendix A) you could make a sprite pass behind a building, say. Of course, it makes fairly lavish use of memory, but the display file is easily split into thirds, and you could use and store just one particular third.

CHAPTER 11
The Attributes File

In the Spectrum, the display file and the attributes file are so cleverly linked — 'transparent' is the computerspeak word — that you are scarcely aware that they are separate and that they do quite different jobs in entirely different ways. You accept that you can print in various colours, on assorted background tints, with only the briefest directions in the PRINT instructions.

However, even in the simplest operations it does no harm to realise what the two files of data are up to. By separating their functions, you can increase the range of possible operations considerably.

The attributes file is really a display file with a much coarser 'mesh'. It only copes with 768d bytes of information, as opposed to the 6144d bytes in the display file dealing with a total of 49,152d pixels.

These relative figures make it clear why individual pixels cannot be coloured separately in the Spectrum — if each pixel had to have a byte of attributes in tandem, we should have used up 60K of RAM straight off, before typing a line of program. (On the Spectrum, you will never be able to have a red spider walking about on a black web.) Even the Sinclair QL, with its lavish memory, only manages four bits per pixel for a full display.

Nonetheless, the attributes are very cleverly arranged. Looking at the attributes as a separate file which can be manipulated independently of the main display file, you can use it as a decision maker, controlling the appearance (or *dis*appearance) of print items in the main display. It provides, for example, an excellent way of keeping track of what is happening at various places on the the screen without letting these be apparent to the eye — hiding things, in fact.

Here is a BASIC program to illustrate what I mean:

Position Hidden in Attributes

```
 10 DIM l$(32)
 20 LET x=INT (RND*32)
 30 PRINT PAPER 0; INK 7;l$
 40 PRINT AT 0,x; PAPER 0; INK 5;" "
 99 STOP
100 FOR j=0 TO 31: IF PEEK (22528+j)<>7
```

```
THEN PRINT j
 110 NEXT j
 199 STOP
 200 PRINT AT 0,0;
 210 FOR j=0 TO 31: PRINT OVER 1; INK 8;
"A";: NEXT j
```

Lines 10 to 50 set up a black line, with 'x' being a randomly-chosen position along it. There is nothing to pick out 'x' on the visible screen — all the positions are the same. But, unseen to us, in the attributes file for that position there is a difference — 'x' has the INK bits set to 5, whereas all the rest are 7. This difference holds, even though there is nothing to print with the INK.

Entering CONTINUE sets in motion a search for the odd byte and prints out the number at which it is found. Entering CONTINUE for a second time reveals the hidden position by printing out a line of 'A's — since they are all white, except for the hidden one, this last alone shows up in cyan.

This 'hide and seek' routine can be very useful in writing all sorts of games. As an example, here is a program to generate a pack of cards and deal them out on the screen — but invisibly (face down, as it were). The section from 100 on 'turns them over'. It reveals them on a white ground with the pips in the appropriate colours. I leave it to you to devise a way to shuffle the cards before dealing, and to prepare the graphics for the pips and the court cards. You will also have to decide what to do about the two cards for which there is no room on the display.

Deal Cards and Reveal

```
   5 LET b=0: LET k=1: LET s=0
  10 FOR i=0 TO 4: FOR j=1 TO 30 STEP 3
  20 LET x$=CHR$ (s+144): LET b=NOT b: L
ET x=1+12*(k-1)
  30 IF k>9 THEN GO TO 200
  40 LET q$=x$+"        "+x$+x$+"   "+
x$+"     "+x$+x$+" "+x$+"     "+x$+" "
+x$+x$+" "+x$+" "+x$+"     "+x$+" "+x$+x$
+" "+x$+x$+" "+x$+"    "+x$+" "+x$+x$+" "
+x$+x$+x$+x$+"    "+x$+" "+x$+x$+" "+x$+x
$+" "+x$+x$+" "+x$+x$+" "+x$+x$+" "+x$+x
$+x$+x$+x$+" "+x$+x$+" "+x$+x$+" "+x$+x$
+x$+x$+x$+x$+x$+x$+" "+x$
  50 PRINT PAPER 3; INK 3; BRIGHT b; OVE
R 1;AT i*4+1,j;q$(x TO x+2);AT i*4+2,j;q
```

```
$(x+3 TO x+5);AT i*4+3,j;q$(x+6 TO x+8);
AT i*4+4,j;q$(x+9 TO x+11)
  60 LET k=k+1: IF k>13 THEN LET k=1: LE
T s=s+1
  70 NEXT j
  80 LET b=NOT b
  90 NEXT i
 100 PAUSE 0
 105 LET k=1: LET c=0
 110 FOR i=0 TO 4: FOR j=1 TO 30 STEP 3
 120 PRINT PAPER 7; INK (2 AND c); BRIGH
T 8; OVER 1;AT i*4+1,j;"   ";AT i*4+2,j;
"   ";AT i*4+3,j;"  .";AT i*4+4,j;"   "
 130 LET k=k+1: IF k>13 THEN LET k=1: LE
T c=NOT c
 150 NEXT j: NEXT i
 199 STOP
 200 IF k=10 THEN LET q$=x$+"  J  J  "
+x$
 210 IF k=11 THEN LET q$=x$+"  Q  Q  "
+x$
 220 IF k=12 THEN LET q$=x$+"  K  K  "
+x$
 230 IF k=13 THEN LET q$=x$+"  A  A  "
+x$
 240 LET x=1: GO TO 50
```

Notice how you can use BRIGHT (in the attributes) to give an outline to two cards which are side by side, even though they may be of the same colour. BRIGHT is a very useful attribute: it gives you an extra palette of six, possibly seven, new tints (black is unaffected, of course, and the difference to blue is negligible) depending on your TV.

The positions of the pips are held in q$, while x$ is set for one of the suits by the variable 's', which is added to the first UDG position.

Unfortunately, this book cannot be illustrated by a printout of the complete screen — the ZX printer simply ignores all the attributes, so all the careful work of hiding and revealing goes for nothing.

The attributes file is laid out in a perfectly straightforward way between 5800h and 5B00h. The first byte in the file stores the attributes for the top lefthand position on the screen and thereafter it runs through them in order, to the bottom right position, 300h (768d) bytes later (see p.164 of the Spectrum manual).

Because the file is laid out in this simple way (as opposed to the display file, of which more in the next chapter) it is very easy to plot your position on the screen and POKE directly into the attributes file.

You can equally easily PEEK into it, to check whether a position is occupied or not. This is one way of getting round the fact that SCREEN$ does not give a result with user graphics. If your graphics character is given a distinctive INK or PAPER colour (or BRIGHT, or FLASH), you can check whether it is on a certain square either by PEEKing the address in the file, or by using ATTR, which calculates the address for you.

Finally, this sensible layout to the attributes file makes it very easy to draw pictures directly to it. Here is a program to do this.

Draw with ATTR

```
10 LET x=16: LET y=10
20 PAUSE 0: LET y$=INKEY$
30 IF CODE y$<48 THEN GO TO 50
40 LET c=CODE y$-48
50 IF CODE y$=8 THEN LET x=x-(x>0)
51 IF CODE y$=9 THEN LET x=x+(x<31)
52 IF CODE y$=10 THEN LET y=y+(y<23)
53 IF CODE y$=11 THEN LET y=y-(y>0)
60 IF CODE y$=13 THEN GO TO 100
70 POKE 22528+x+y*32,c*8
80 GO TO 20
```

In line 10, 'x' and 'y' set a start position in the centre of the screen and print a coloured square. The 'x > 0', 'x < 31', etc., are a way of stopping the printed square running off the screen. They are logical functions which are worth 1 if they are true and 0 if they are not. So 1 will be added to x or y, only if they fall between the set limits (as described in Chapter 8). The program will give you the full 24 screen lines to play with.

The program first sets a colour at line 30, after which you must use the cursor keys with CAPS SHIFT to move the square about. If you hold down a key, the repeat operates. I have not included coding for diagonal moves, but there is a similar program in Appendix A (PaintCODE) which illustrates how this can be done.

The result comes out like a bright and satisfying kind of finger painting and is ideal for drawing backgrounds for print displays, or whatever. Remember that, as you have been dealing only with the attributes, ordinary printed characters can be compiled and displayed over the background quite independently, although you will have to include 'PAPER 8; INK 9', to make sure that they don't import their own attributes with them.

Your impressionist masterpiece needs to be stored somehow, if it is not to be lost as soon as you LIST your programming. You *can* do this with the Spectrum's SAVE ...SCREEN$. However, it takes a terribly long time to do the SAVEing (and to LOAD it) and you will be SAVEing all the print display file as well, which you don't really want in the present case.

It is quicker and neater to copy the whole attributes file somewhere else in the RAM, and SAVE it as a block of data, with 'SAVE ATTRfile CODE xxxxx,768'. This takes a fraction of the time of SCREEN$ and puts the copy file somewhere where it can be called up at will during your program.

You can make the copy using a BASIC program like:

Store ATTR File at F000h (61440d)

```
10 FOR j=0 TO 768
20 POKE 61440+j,PEEK (22528+j)
30 NEXT j
```

A machine code program, though, is even simpler. It works in the twinkling of an eye, rather than about 10 seconds, as does the reverse program which will put your design back on the screen whenever you want it.

Store Attributes File at F000h

```
F500 21 00 58    LD    HL,5800
F503 11 00 F0    LD    DE,F000
F506 01 00 03    LD    BC,0300
F50B C9          RET
```

Restore Attributes File from F000h

```
F50C 21 00 50    LD    HL,5000
F50F 11 00 F0    LD    DE,F000
F512 11 00 03    LD    BC,0300
F515 ED B0       LDIR
F517 C9          RET
```

The two routines (using the addresses I have given) are called by 'USR 62720' and 'USR 62732'.

The 768d bytes used to store the attributes file do not take up a large amount of extra RAM — especially when compared with the 6144d bytes for the print display file. However, they do store a good deal of redundant information for our purposes — we are only interested in the PAPER colours. It is quite possible to extract the PAPER information and store this in 288d bytes, by itself.

Colour

The method of storing these colour bits leads us into the territory of colour reproduction in general. Photography, printing and computer displays all follow the same principles for colour. This is not altogether surprising, since our own colour vision depends on the presence or absence of three primary colours, which is the principle employed in the colour reproduction systems I've mentioned.

To deal with the general principles first. The Spectrum stores PAPER colours in bits 3, 4 and 5 of each attributes byte (see p.116 of the Spectrum manual). The first of these bits codes for blue, the second for green, and the third for red. Ignoring the fact that the bits have been shifted three positions to the left, the three primary colours are coded by setting bit 1 for blue, bit 2 for red and bit 3 for green, giving them positional values of 1, 2 and 4. Now look at the colours over the numeral keys on the Spectrum. Neat, isn't it?

The other three colours are combinations of two primary colours: they are called 'complementary colours' and are known as cyan (from the name of the dye originally used to produce it in photography), magenta and yellow. White is a combination of all three. These check out on the keyboard, too.

The complementary colours are also known as 'minus' colours, because magenta is '(white) minus green', yellow is 'minus blue' and cyan is 'minus red'.

You may be wondering what all this has to do with the Spectrum but all will shortly be revealed in a blinding flash, because if we peel off all the ATTR bits at position 3 and store them, we have, in fact, stored the blue image. The bits at position 4 will store the green image; and the bits at position 5 will store the red image. The complementary colours will be stored in the appropriate pairs of blocks and white in all three.

To restore the bits to the screen in the correct colours, we can either *add* the primaries on a black screen (in computer terms, set the primary bits in a blank byte), or we can *subtract* the complementary colours from a white screen, which means we reset the complementary pairs of bits in a byte where the bits are all initially set.

All these exercises can be done using the logical functions of the Z80 chip. Some programs to carry them out follow. Most of the hard work lies in getting the bits and bytes into the right order and the right position.

The first routine is a little more complicated than it need be, because I have arranged for the 'PAPER colour' bits, which we collect and store, to be arranged as 'characters' so that they can be printed out as UDGs. This shows the complete screen compressed into a block of 4 × 3 characters.

The actual testing is done by checking whether bit 3 (the blue bit) of each ATTR byte is set. If it is, we set a bit in the A register and eventually transfer the completed byte in A to a storage position. Meanwhile, we have shifted the whole ATTR file one bit to the right, so that bit 4 becomes bit 3. When we perform the operation again, the red bits will have been stored. At the end of the second round, ATTR will have been shifted again, so that the green bit becomes bit 3.

We restore the whole attributes file at the end of the routine.

3-colour Separations of ATTR

```
F000  11 00 F1   LD    DE,F100    START OF STORAGE ADDRESS
F003  06 03      LD    B,03       COUNT FOR 3 PASSES = BLUE,
                                    RED, GREEN
F005  C5         PUSH  BC
F006  21 00 58   LD    HL,5800    START OF ATTR
F009  0E 03      LD    C,03       VERTICAL — 3 PRINT POS.
F00B  06 08      LD    B,08       VERTICAL — 8 LINES PER PRINT
                                    POS.
F00D  C5         PUSH  BC
F00E  D5         PUSH  DE
F00F  0E 04      LD    C,04       HORIZONTAL — 4 PRINT POS.
F011  06 08      LD    B,08       HORIZONTAL — 8 BITS PER
                                    PRINT POS.
F013  AF         XOR   A
F014  CB 5E      BIT   3,(HL)     TEST BIT 3 ATTR
F016  28 01      JR    Z,F019     JUMP IF NOT SET
F018  37         SCF              SET CARRY IF BIT 3 SET
F019  17         RLA              GET CARRY INTO A
F01A  CB 0E      RRC   (HL)       SHIFT ATTR TO GET BIT 4 INTO
F01C  23         INC   HL           BIT 3 POS.
F01D  10 F5      DJNZ  F014
F01F  12         LD    (DE),A     TRANSFER A TO STORAGE BYTE
F020  C5         PUSH  BC         }
F021  EB         EX    DE,HL      }
F022  0E 08      LD    C,08       }
F024  09         ADD   HL,BC      } MOVE STORAGE ADDRESS
F025  EB         EX    DE,HL      }   8 BYTES = NEXT UDG
F026  C1         POP   BC         }
F027  0D         DEC   C
F028  20 E7      JR    NZ,F011    REPEAT OPERATION FOR
                                    4 UDG
F02A  D1         POP   DE
F02B  13         INC   DE         ADDRESS NEXT BYTE OF
                                    UDG CHRS
```

```
F02C C1          POP  BC
F02D 10 DE       DJNZ F00D         REPEAT ALL OPS FOR 8
                                     BYTES PER CHR
F02F C5          PUSH BC          }
F030 EB          EX    DE,HL      }
F031 0E 18       LD    C,18       } MOVE STORAGE ADDRESS
F033 09          ADD  HL,BC       }   TO NEXT GROUP OF 4 CHRS
F034 C1          POP  BC          }
F035 EB          EX    DE,HL
F036 0D          DEC  C
F037 20 D2       JR    NZ,F00B     REPEAT ALL OPS 3 TIMES
                                     FOR 3 GROUPS OF 4
F039 C1          POP  BC
F03A 10 C9       DJNZ F005         REPEAT WHOLE 3 TIMES
                                     FOR BLUE, RED, GREEN
F03C 01 00 03    LD    BC,0300    }
F03F CB 06       RLC  (HL)        }
F041 CB 06       RLC  (HL)        }
F043 CB 06       RLC  (HL)        }
F045 2B          DEC  HL          } RESTORE SHIFTED ATTR
F046 0B          DEC  BC          }   FILE TO ORIGINAL STATE
F047 78          LD    A,B        }
F048 B1          OR    C          }
F049 20 F4       JR    NZ,F03F    }
F04B C9          RET
```

The three blocks of characters should now be stored in the RAM, starting at F100h (61696d) for the blue, F160h (61792d) for the red and F1C0h (61888d) for the green. The routine is placed at F000h, which is 61440d.

Here is a BASIC program to execute the machine code routine and then display the three miniature 'colour separation' images. To print out these images, the program POKEs the requisite addresses into the system variable UDG, at 5C7Bh and 5C7Ch (23675d and 23676d). Tack it on to the BASIC 'Draw with ATTR' program.

Generate and Print out Colour Separation Images

```
100 RANDOMIZE USR 61440
110 POKE 23675,0: POKE 23676,241
120 PRINT INK 8; INVERSE 1;"ABCD"'"EFGH
"'"IJKL"
130 POKE 23675,96
140 PRINT INK 8; INVERSE 1;"ABCD"'"EFGH
"'"IJKL"
150 POKE 23675,192
```

```
160 PRINT INK 8; INVERSE 1;"[illegible]"'"[illegible]"'"[illegible]"
```

The printout in **Figure 11.1**, with letters for the colours, shows how the separations take shape. Each miniature pattern depicts a minus colour. The border, being black, shows up in each of them. If you could make transparencies of these miniatures and view them, one on top of the other, you would get full colour reproduction of the original pattern.

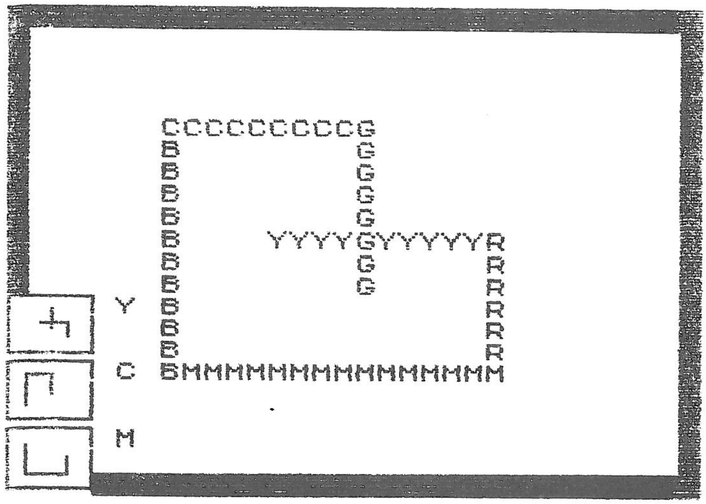


Figure 11.1

In the meantime, let's write a routine to put the attributes together again. Here it is.

Reconstitute in ATTR

```
F050 DD 21 60 F1 LD    IX,F160      ADDRESS FOR 'RED' IMAGE
F054 21 00 58    LD    HL,5800      ATTR FILE
F057 0E 03       LD    C,03         } 1
F059 06 08       LD    B,08         } 2
F05B C5          PUSH  BC           } CONTROL LOOPS
F05C DD E5       PUSH  IX           }
F05E 0E 04       LD    C,04         } 3
F060 06 08       LD    B,08         } 4
F062 DD CB A0 06 RLC     (IX-60)    'BLUE' STORAGE ADDRESS
F066 38 02       JR      C,F06A
F068 CB 9E       RES   3,(HL)       CANCEL 'BLUE' BIT =
                                    YELLOW IMAGE
```

```
F06A DD CB 00 06 RLC      (IX)       'RED' STORAGE ADDRESS
F06E 38 02       JR        C,F072
F070 CB A6       RES   4,(HL)        CANCEL 'RED' BIT = CYAN
                                       IMAGE
F072 DD CB 60 06 RLC      (IX+60)    'GREEN' STORAGE ADDRESS
F076 38 02       JR        C,F07A
F078 CB AE       RES   5,(HL)        CANCEL 'GREEN' BIT =
                                       MAGENTA IMAGE
F07A 23          INC   HL
F07B 10 E5       DJNZ  F062           LOOP 4
F07D 11 08 00    LD    DE,0008
F080 DD 19       ADD   IX,DE
F082 0D          DEC   C
F083 20 DB       JR     NZ,F060      LOOP 3
F085 DD E1       POP   IX
F087 DD 23       INC   IX
F089 C1          POP   BC
F08A 10 CF       DJNZ  F05B          LOOP 2
F08C 1E 18       LD    E,18
F08E DD 19       ADD   IX,DE
F090 0D          DEC   C
F091 20 C6       JR     NZ,F059      LOOP 1
F093 C9          RET
```

As you can see, this routine relies heavily on the indexed register IX. This allows us to access the stored colour information in the same way right through. The offsets between equivalent positions in the three colour images always remain the same.

The base address for IX points to the 'green' store. This is the middle one of the three. I have done this because the register can only index forward 128 bytes. Since each colour store contains 96 bytes, it would not be possible to index forward to the third colour from the first. However, you can index *backwards* by 127 bytes as well, so by choosing the middle position you can reach all three store addresses.

Before we finally leave the attributes, I'd like to point out that the techniques we have been talking about could be a very handy method of producing miniature drawings for sprites. Many people find it easier to do the drawings on a full-sized TV screen and then scale them down to sprite size. You could even try and use the colour separations to produce a cycle of three drawings for animation. But I suspect that, by the time you had worked out the colour relationships, you might just as well have designed each one from scratch.

However, if you wanted to try, here is a BASIC program to change the colours of an attributes painting on the screen:

Turn Designs Red or Green

```
  99 REM Turn image red
 100 FOR j=0 TO 768: IF PEEK (22528+j)<>
7*8 THEN POKE 22528+j,16
 110 NEXT j
 190 PAUSE 0
 199 REM Turn image green
 200 FOR j=0 TO 768: IF PEEK (22528+j)<>
7*8 THEN POKE 22528+j,32
 210 NEXT j
```

CHAPTER 12
The Display File

While the attributes file is of interest, the main print display file is far more important in the normal use of the Spectrum. At a pinch, you could get by without the attributes at all, but without the main display file the computer would be virtually blind and dumb.

Before you can start manipulating the main Sinclair display file, you have to understand how it works. Alas, as has already become clear, it is nothing like as straightforward as the attributes file. Apart from being very much longer, it is laid out in a notoriously unconventional way (see Chapter 9). You need a clear head to map your way about the screen. No wonder the Spectrum manual remarks primly, 'It is rather curiously laid out, so you probably won't want to PEEK or POKE in it.' Unfortunately, you probably will....

In dealing with sprites, we made a lot of use of the ROM routine PIXEL__AD, in order to pinpoint the screen address once we had the x and y PLOT coordinates. But if you want, for example, to scroll the whole screen, pixel by pixel, this routine is not really the answer.

Bearing in mind the mental model I described in Chapter 9 (with the 'long character lines') let's look again at the make-up of a column of print positions.

In printing a black column or bar down the screen, you are POKEing a series of addresses in the display file with the value FFh (255d). If we start at the top lefthand corner of the screen, the first address is 4000h (16384d). Then we have to add 100h (256d) for the next seven positions, which are the beginning of a line, in a group of long lines. After that, we have to backtrack to position 32 on the first long line to get the next vertical position below the last, on the screen. (Look again at **Figure 9.1** in Chapter 9.)

We then go through the same operation of adding 100h eight times, as we did before, and again find a position 20h along for the next group of lines... up to eight times in all. Then we have to tackle the next group of long lines, starting at the base address plus 800h (2048d)... And then the third.

Actually, in a BASIC program, it's not too bad:

POKE Vertical Bar to Screen

```
10 LET x=16384
20 FOR z=0 TO 2
30 FOR i=0 TO 7
40 FOR j=0 TO 7
50 POKE x+256*j+32*i,255
60 NEXT j: NEXT i
70 LET x=x+2048: NEXT z
```

You can see rather clearly how the loops of 8, 8 and 3 are nested together. The same holds true for the machine code version, although the different sections of the counts are tested by logical ADDing, so that it is not so easy to follow.

Print Vertical Bar

```
E000 21 10 40     LD    HL,4010
E003 06 C0        LD    B,C0
E005 3E FF        LD    A,FF
E007 77           LD    (HL),A
E008 24           INC   H
E009 7C           LD    A,H
E00A E6 07        AND   07          TEST FOR BOTTOM
E00C 20 0A        JR    NZ,E018      OF LONG LINE
E00E 7D           LD    A,L
E00F C6 20        ADD   A,20
E011 6F           LD    L,A         GET NEXT POS. ON
E012 3F           CCF                LONG LINE
E013 9F           SBC   A,A
E014 E6 F8        AND   F8          CORRECT FOR EACH
E016 84           ADD   A,H          THIRD OF SCREEN
E017 67           LD    H,A
E018 10 EB        DJNZ  E005
E01A C9           RET
```

Finding UDGs

Before we go on to what bureaucrats would probably like to call an 'in-depth analysis of the screen situation', the addressing method I have just outlined does offer help in a particular area where the Spectrum fails.

The manual tells us, on p. 101, that SCREEN$ does not recognise UDGs. As bad luck would have it, these are exactly the characters we are most likely to want to look for. However, we now know how to follow, say, the top line of character bytes through the display file, and we can use this to spot a UDG, if we prepare it properly.

Cast your mind back to the pack of cards we were discussing a few pages ago. I have made some designs for the four suits, which can be entered into the UDGs. They look quite convincing, as you can see from **Figure 12.1**.

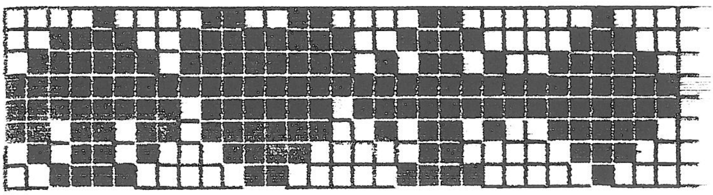


Figure 12.1: Designs for Card Suits

If you look at the big characters in the grid, you will see that the top line of each suit is different from each of the others, which means that when they are in the display file the top byte at their print position will be identifiable. Here are the values of these bytes:

Spade	08h	8d
Heart	66h	102d
Club	18h	24d
Diamond	10h	16d

You can look for them with the program below, which will put a coloured square on the first occurrence. Incidentally, none of the Sinclair characters use any of these combinations for their first lines — most of them are blank, but © is 3Ch (60d).

Locate Suit

```
  5 PRINT AT 8,5;"♠ ♥ ♣ ♦"
 10 FOR i=0 TO 2: FOR j=0 TO 25
 20 IF PEEK (16384+j+i*2048)=16 THEN GO
TO 40
 30 NEXT j: NEXT i
 40 PRINT AT i*8+INT (j/32),j-32*INT (j
/32); OVER 1; PAPER 4;" "
```

You are more likely, however, to want to identify a suit at a position you already know. In that case, you would use a routine like the following one, which will add the correct colour to the graphic character at the chosen position.

Check Top Line

```
   1 REM x=COLUMN  y=LINE
1010 LET zone=INT (y/8)
1020 LET y1=y-8*zone
1030 LET p=16384+zone*2048+y1*32+x
1040 PRINT INK 2 AND (PEEK p=16 OR PEEK
p=102);
```

The variable 'zone' identifies which third of the screen we are looking at.

Scrolling

There is one other operation to do with the display file which is not difficult, and that is to scroll the file to the left or to the right. (I'm talking of a pixel scroll rather than a full print position, which is not really a problem, anyway.)

The reason why the pixel scroll is easy is that, as you are not changing the line positions, it does not matter in what order you take them — you can simply start at the top and work down to the bottom.

To do the scroll, you take each byte of the display file in turn (addressed by HL), do a 'rotate (HL)' — either left or right — and move on to the next. The only thing you have to remember is that you must start at the *end*, if you are scrolling to the left and at the *beginning*, if you are scrolling to the right. This is to allow the bits that drop off the end of each character to be picked up and put in the correct position in the next character.

Here is the simplest sort of scroll. You have to provide two loops — ie do the scroll a line at a time — so that you have a chance to wipe out the last carry of the line. If you don't do this, the print will scroll back on to the screen, turning up at some very peculiar places. Try it for yourself, by substituting '00' for 'AF', at F007h.

Scroll Screen to Left

```
F000 21 FF 57    LD    HL,57FF
F003 0E C0       LD    C,C0
F005 06 20       LD    B,20
F007 AF          XOR   A
F008 CB 16       RL    (HL)
F00A 2B          DEC   HL
```

```
F00B 10 FB        DJNZ F008
F00D 0D           DEC  C
F00E 20 F5        JR   NZ,F005
F010 C9           RET
```

To get it to scroll the other way, change the first line to '21 00 40', change line F008h to 'CB 1E' and the next instruction from '2B' to '23'.

Scrolling is not much fun unless you have something to *scroll on*, as well as scroll off. This means having another display file prepared at another address.

As an example, here's a routine to scroll two screens round and round, like a revolving drum. It could be useful for providing a moving background to something.

Drum Scroll — Right to Left ✓

```
F000 11 FF E7     LD   DE,E7FF   ←
F003 21 FF 57     LD   HL,57FF   ←
F006 F5           PUSH AF
F007 0E C0        LD   C,C0
F009 F1           POP  AF
F00A E5           PUSH HL
F00B 06 20        LD   B,20
F00D AF           XOR  A
F00E 7E           LD   A,(HL)
F00F 17           RLA            ←
F010 77           LD   (HL),A
F011 2B           DEC  HL        ←
F012 10 FA        DJNZ F00E
F014 06 20        LD   B,20
F016 1A           LD   A,(DE)
F017 17           RLA            ←
F018 12           LD   (DE),A
F019 1B           DEC  DE        ←
F01A 10 FA        DJNZ F016
F01C E3           EX   (SP),HL
F01D 3E 00        LD   A,00
F01F 17           RLA            ←
F020 B6           OR   (HL)
F021 77           LD   (HL),A
F022 E3           EX   (SP),HL
F023 F1           POP  AF
F024 F5           PUSH AF
F025 0D           DEC  C
```

```
F026  20 E1        JR     NZ,F009
F028  F1           POP    AF
F029  C9           RET
```

61488

Transfer Second Display to D000h

```
F030  21 00 40     LD     HL,4000
F033  11 00 D0     LD     DE,D000
F036  01 00 18     LD     BC,1800
F039  ED B0        LDIR
F03B  C9           RET
```

61504

Scroll One Complete Screen

```
F040  01 00 00     LD     BC,0000
F043  C5           PUSH   BC
F044  CD 00 F0     CALL   F000
F047  C1           POP    BC
F048  10 F9        DJNZ   F043
F04A  C9           RET
```

The main program is really just two versions of the earlier program spliced together. The visible display file is at 4000h and the second one is at D000h. HL holds the address of the first, and DE holds the second. (Remember, we are starting at the end, so the initial addresses are 57FFh and E7FFh.)

There's an interesting little operation at F01C–F024h. At the end of the line, we are left with a dangling carry bit. It has dropped off the last byte and has to be tacked on to the first byte of the line, if the continuous movement is to be preserved. To do this, we PUSH the address of the first byte, early on (at F00Ah), because by the time we get to F01Ch we have a new address in HL, which we want to keep. There's nowhere to PUSH the new address, so we swap it with the first address, still on the top of the stack and get whatever was in the carry into the byte at this address. Then we swap the HL addresses once again and throw away the first one (the address of the first byte) by POPping it into AF and get on with the job.

The arrows in the routine point to the bytes which have to be changed, if you want to change the direction of the scroll. Here they are, tabulated:

	R to L	*L to R*
F000–02	11 FF E7	11 00 D0
F003–05	21 FF 57	21 00 40
F00F	17 RLA	1f RRA
F011	2B DEC HL	23 INC HL

```
F017        17    RLA        1F    RRA
F019        1B    DEC DE     13    INC DE
F01F        17    RLA        1F    RRA
```

The other two short routines are for use in connection with the main one. The first transfers whatever is on the screen to the second display file, which we create at D000h. The other is a demonstration program which will completely scroll from one screen to the other: the operation takes exactly 256 cycles, from B = 0 to B = 0.

Rearranging the file

Scrolling the screen sideways, as you can see, is a fairly painless operation. However, if we want to scroll up and down, we are tangled again with that nightmare of jumping from line to line. After struggling with it for some time, I have come to the conclusion that the only sensible course is to rewrite the entire display file at another address and to rearrange it in a way which makes it possible to deal with. That is with line 2 coming after line 1, line 3 after line 2, and so on.

In this way, we only have two short routines to deal with all situations — one to rearrange the data in the shape we want it and the other to reconstitute the display file and get it back on the screen.

The routines are very much like the Print Vertical Bar routine at the beginning of this chapter, with the added factor of dealing with a complete line of bytes, rather than a single one. Here is the first:

Rearrange D/File at D000–D800h

```
F000 21 00 40     LD    HL,4000
F003 11 00 D0     LD    DE,D000
F006 0E C0        LD    C,C0

F008 E5           PUSH  HL
F009 06 20        LD    B,20
F00B 7E           LD    A,(HL)
F00C 12           LD    (DE),A
F00D 23           INC   HL
F00E 13           INC   DE
F00F 10 FA        DJNZ  F00B

F011 E1           POP   HL
F012 24           INC   H
F013 7C           LD    A,H
F014 E6 07        AND   07
F016 20 0A        JR     NZ,F022
```

```
F018 7D          LD     A,L
F019 C6 20       ADD    A,20
F01B 6F          LD     L,A
F01C 3F          CCF
F01D 9F          SBC    A,A
F01E E6 F8       AND    F8
F020 84          ADD    A,H

F021 67          LD     H,A

F022 0D          DEC    C
F023 20 E3       JR      NZ,F008
F025 C9          RET
```

Writing the program to restore the display file is even less arduous: you make a copy of the first program at a new address (I have chosen F030h). If you have a good assembler or editing program, you can probably do this automatically. Then you alter just two instructions: you change 'LD A (HL)', at F03Bh, into 'LD A (DE)' and you change 'LD (DE)A', at F03Ch, into 'LD (HL)A'.

Restore D/File from D000–D800h

```
F030 21 00 40    LD     HL,4000
F033 11 00 D0    LD     DE,D000
F036 0E C0       LD     C,C0

F038 E5          PUSH   HL
F039 06 20       LD     B,20
F03B 1A          LD     A,(DE)
F03C 77          LD     (HL),A
F03D 23          INC    HL
F03E 13          INC    DE
F03F 10 FA       DJNZ   F03B

F041 E1          POP    HL
F042 24          INC    H
F043 7C          LD     A,H
F044 E6 07       AND    07
F046 20 0A       JR      NZ,F052

F048 7D          LD     A,L
F049 C6 20       ADD    A,20
F04B 6F          LD     L,A
F04C 3F          CCF
F04D 9F          SBC    A,A
F04E E6 F8       AND    F8
```

```
F050 84          ADD   A,H
F051 67          LD    H,A
F052 0D          DEC   C
F053 20 E3       JR     NZ,F038
F055 C9          RET
```

Armed with these two routines, a whole range of screen manipulations becomes possible. Up and down scrolling, pixel by pixel, becomes a simple LDIR instruction, and you can easily scroll sections of the screen (any section, not just thirds), or even windows.

It is equally easy, of course, to scroll from side to side — you could quite well replace the Drum Scroll routine we discussed earlier, but then you would have to have *two* spare display files on the go at the same time, which seems rather lavish for what you are trying to do.

Here is a more exotic diagonal scroll, with a little routine to run it continuously.

Diagonal Screen Scroll

```
F100 21 20 D0    LD    HL,D020
F103 11 00 D0    LD.   DE,D000
F106 01 E0 17    LD    BC,17E0
F109 CB 1E       RR    (HL)
F10B ED A0       LDI
F10D EA 09 F1    JP    PE,F109
F110 C3 30 F0    JP    F030
```

Repeat Routine

```
F200 06 A0       LD    B,A0
F202 C5          PUSH  BC
F203 CD 00 F1    CALL  F100
F206 C1          POP   BC
F207 10 F9       DJNZ  F202
F209 C9          RET
```

Do not, as I did, forget to include the 'PUSH BC' and 'POP BC' to preserve the count in the second program — to see the entire listing disappear majestically into the righthand corner, never to be seen again!

Shrinking the screen

These are only small samples of the freedom given by our rearranged display file. There is no problem in shrinking a screen down to quarter size, as shown in **Figure 12.2**.

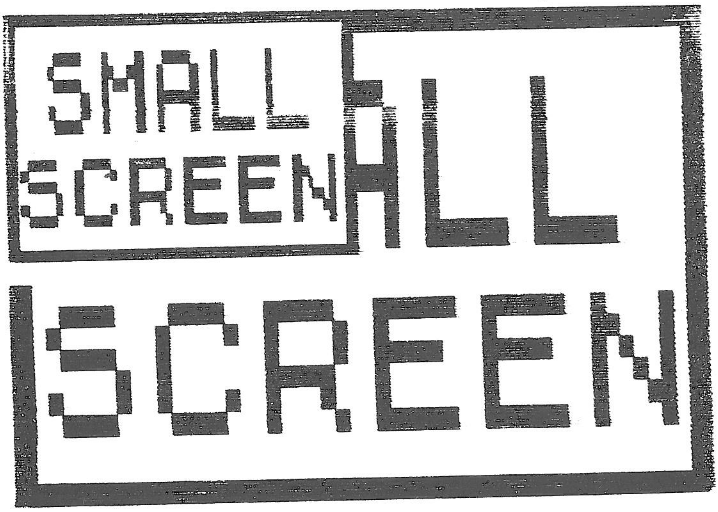


Figure 12.2

The routine reproduced here is a fairly 'coarse mesh' one — it just squeezes together all the righthand nibbles, using the 'rotate left decimal' instruction and skips every alternate line. It will only work with a fairly bold design, such as the one I have used. But it would not be at all difficult to pick up alternate bits from the original file, to give a better resolution, rather as we did to generate the 'four-bit character' font. However, I don't think print would ever be legible with the letters compressed into a 4 × 4 matrix.

Make Quarter-sized Screen

```
F060 11 00 D0      LD    DE,D000
F063 21 00 D0      LD    HL,D000
F066 0E 60         LD    C,60
F068 06 10         LD    B,10

F06A 1A            LD    A,(DE)
F06B ED 6F         RLD
F06D 13            INC   DE
F06E 1A            LD    A,(DE)
F06F ED 6F         RLD
F071 13            INC   DE
F072 23            INC   HL
F073 10 F5         DJNZ  F06A

F075 C5            PUSH  BC
F076 01 20 00      LD    BC,0020
```

```
F079 EB          EX   DE,HL
F07A 09          ADD  HL,BC
F07B EB          EX   DE,HL
F07C 0E 10       LD   C,10
F07E 09          ADD  HL,BC
F07F C1          POP  BC
F080 0D          DEC  C
F081 20 E5       JR   NZ,F068
F083 C3 30 F0    JP   F030
```

CHAPTER 13
Inputs and Outputs

I sometimes forget that the Spectrum is not self-contained. But if it were not for a number of input and output devices by which it is served, the computer would be of no practical use.

The standard input devices are the keyboard and the cassette recorder, or Microdrive. Output devices are the television, the recorder (or Microdrive, once again) with the beeper and the printer. Many other I/O devices can be added, of course — joysticks, paper printers and whatnot. But they all require special interfaces, and, in this book, I want to look at methods of using the different devices which make up the *standard* Spectrum, in ways that Sinclair Research did not intend.

I can say straight away that there is nothing much to be done with the recorder and the television, as such (as opposed to the information we send them). Nor is there much to be gained by tinkering with the output to the printer, to say nothing of the danger of tying the computer in a knot, and so I will not be dealing with these devices in this chapter.

The areas that are worth exploring are the output to the border of the television screen, which is normally controlled by the 'BORDER x' command, and to the beeper.

Even in these areas, the scope is limited. You can turn the border into an imitation of a Neapolitan icecream, if that appeals, or make the screen 'explode'. Or you can modify the single note BEEP, to give a range of catcalls and whistles. To make some of these tricks more effective, we can also change the interrupt mode.

Perhaps this should be explained first.

The interrupt mode

In normal operation, the Spectrum hardware 'interrupts' the work of the Z80 microprocessor every 20 microseconds (50 times a second). This means that the Z80 stops whatever it is doing and goes into an interrupt routine, which has to be completed before it can get on with its main task.

This interrupt routine is fixed in the ROM at 0038h, and consists of a quick update on the Spectrum timer, at 'FRAMES', followed by a keyboard scan, to see what keys are depressed.

The Z80 microprocessor is designed to allow these interrupts, to carry out precisely this type of regular operation. It has, in fact, three kinds (or modes) of interrupt, known as IM0, IM1 and IM2. There is also a 'non-maskable', ie unstoppable, interrupt, NMI.

IM0 can't be used by the Spectrum. IM1 is the mode normally used to do the keyboard scan, etc.: it causes a direct jump to the start of the routine at 0038h, the 'RST 38' instruction. The all-powerful NMI has been blocked— apparently deliberately—in the Sinclair ROM. Which leaves only IM2 to consider.

Let's see what IM2 does. When the Z80 has been programmed for the IM2 mode and an interrupt occurs, the Z80 immediately concocts an address. This address is made from a low order byte, taken from the gadget which did the interrupting — the Sinclair ULA — and a high order byte, taken from the contents of the I register, an esoteric register provided by the Z80 for this purpose.

Having put together this address, the Z80 then jumps to it, hoping to find *another* address put there by the programmer. It then proceeds to execute whatever routine it finds at this second address.

This sounds very complicated, but the purpose is to allow the micro-processor to tackle a particular routine dictated by a particular peripheral.

Now, what can we do with that? When an interrupt occurs, the ULA is not programmed to supply any particular byte, so the default byte on the bus should be 'FF'.

This means that the address which IM2 will concoct will be 'xxFF', where 'xx' has to be what IM2 finds in the I register. And this is something *we* can put there.

For complicated hardware reasons, the complete address should not be placed between 4000h and 7FFFh, which—as bad luck would have it—is the entire RAM area for the 16K Spectrum! However, 16K owners should not despair yet.

48K owners are free to choose any xxFF address they like above 8000h and put into it the address of the interrupt routine they have written: ie if your interrupt routine is at F001h, then you could place this address at EFFFh, in the form:

```
EFFF    01
F000    F0
```

So what you have to do is to set the interrupt mode as IM2, load I with (in the present case) 'EF' and provide a suitable routine at F001h. The Spectrum will then carry out this routine every time an interrupt occurs, in the middle of whatever else you have programmed it to do.

If you want the program to continue updating the clock and scanning the keyboard, then you should make it jump to 0038h when your own routine is finished. Otherwise, you do an 'enable interrupts' ('FB'), followed by RET, or RETI.

An important point to note is that *you must save all the registers* to be used during the interrupt routine, including AF and the alternate registers if used. They must all be PUSHed at the start and then POPped again before the finish.

16K owners may be feeling a bit disheartened at the moment, but there is a dodge which allows them to join in. It is possible to use an address in the ROM. Of course, the ROM can't be modified, but you can look for two adjacent bytes which are at 'xxFF' and 'xxFF+1', and which together hold a viable address in the spare RAM.

This search yields the following results, when looking for addresses in the ROM greater than A000h, at xxFFh locations:

'xxFF' Addresses in ROM (48K)

511	01FF	CE52
2559	09FF	FE69
3071	0BFF	E608
3327	0CFF	CFBF
3583	0DFF	CD17
4351	10FF	CB10
4863	12FF	CD01
5119	13FF	C255
5631	15FF	C9D9
5887	16FF	C970
7423	1CFF	C31B
8447	20FF	CD21
9215	23FF	C181
10751	29FF	E32A
11775	2DFF	D9E5
12543	30FF	EB30
12799	31FF	E128
13823	35FF	DF24
14335	37FF	A10F
14591	38FF	FFFF
14847	39FF	FFFF
15103	3AFF	FFFF
15359	3BFF	FFFF
23551	5BFF	FF00

Another list more suitable for the 16K Spectrum, goes as follows:

'xxFF' Addresses in ROM (16K)

1791	71DD	06FF
4095	0FFF	6D18

5375	14FF	6469
7935	1EFF	67CD
10495	28FF	7E5C
24063	5DFF	6964
24831	60FF	79A2

There is quite a wide choice. Almost the highest practical address for the 48K Spectrum comes at 09FFh, where there is 'FE69h'. 16K owners could try 28FFh, which yields '7E5Ch'.

I say 'almost the highest practical address', because 48K owners have a final, rather jokey choice; they can use FFFFh! Oddly, although FFFFh is the absolute end of the RAM, you don't just fall off into space after that: you simply go round again. So that the address after FFFFh, for practical purposes, is 0000h. And this pair yield quite a useful address for an interrupt routine, 'F300h'.

```
FFFF    00   (you can change this)
0000    F3
```

There are two further notes of caution to be sounded. (After all, we are *not* doing what Sir Clive intended!) First, there is nothing that says that the byte on the input buffer has to be 'FF'. It usually is, but if you have some other gadgets hooked up, it may be different. It could be anything at all. (This snag, luckily, does not arise with the Microdrive.)

Faced with this problem, you would have to provide a complete range of bytes, 257 in all, any pair of which will give the same address. For example, you might choose the byte 'FE'. Paired together, this would provide an address 'FEFE' at which you could put your interrupt routine.

You would have to load all the bytes from, say, FD00h to FE00h with FE. Then you would have to get the byte FD into the I register, after which it wouldn't matter *what* other byte got provided for the vector address, this would always produce FEFE.

Secondly, proceed with extreme caution when using ROM addresses when the Interface 1 is connected. The Spectrum may refer the vector address to the Interface 1 ROM, with hopeless results. Alas, I know of no way round this problem except to disconnect the Interface.

We have now reached the stage when we want to be able to set the interrupt mode and supply the byte in I. The following would be the sort of routine, using a ROM address:

Set Interrupt Mode 2 not work on 128K+2a

```
F000 3E 09          LD    A,09
F002 ED 47          LD    I,A
```

```
F004 ED 5E        IM2
F006 C9           RET
```

We also need a similar piece of machine code, to restore the status quo, once we have finished using our interrupt program.

Restore Interrupt Mode 1

```
F010 3E 3F        LD    A,3F
F012 ED 47        LD    I,A
F014 ED 56        IM1
F016 C9           RET
```

The programs we set up at the interrupt address FE69h can be anything within reason. However, it has to be remembered that the Z80 cannot get on with the main routine while it is attending to the interrupt routine, so the main routine will be slowed down.

The main problem with the interrupt switch, which really limits its use, is the fact that we are tinkering with the wrong thing. You really want to be able to control the *timing* of the interrupt, as much as the interrupt routine: there is a limit to the number of things you want to check regularly 50 times a second. It would be much more useful to have the interrupt under our own control, in order to exploit it fully. But this is not possible, so we should be thankful for what we have.

The television screen

Here is a program to turn the television border into a Neapolitan icecream.

Neapolitan Ice Border

```
FE69 F5           PUSH  AF
FE6A C5           PUSH  BC
FE6B 06 08        LD    B,08
FE6D 0E 00        LD    C,00
FE6F 78           LD    A,B
FE70 3D           DEC   A
FE71 D3 FE        OUT    (FE),A
FE73 00           NOP
FE74 00           NOP
FE75 00           NOP
FE76 0D           DEC   C
FE77 20 F9        JR     NZ,FE72
```

```
FE79 10 F2        DJNZ FE6D
FE7B C1           POP  BC
FE7C F1           POP  AF
FE7D C3 38 00     JP   0038
```

The NOPs are there to cause a delay, so that the colours in the border are evenly spaced out.

Another quite jolly variation is the following, which makes the screen appear to explode, by switching the colours every time a new frame appears:

Flashing Border

```
FE69 F5           PUSH AF
FE6A 3A 81 5C     LD   A,(5C81)
FE6D D3 FE        OUT   (FE),A
FE6F 3D           DEC  A
FE70 20 02        JR    NZ,FE74
FE72 3E 08        LD   A,08
FE74 32 81 5C     LD   (5C81),A
FE77 F1           POP  AF
FE78 C3 38 00     JP   0038
```

Probably the most useful application of the changed interrupt is to allow you to provide a moving background, independent of other program activity, in the course of a game (such as the Drum Scroll program described in Chapter 12).

The Spectrum BEEP

There is one other area where some worthwhile input/output techniques can be put into practice, and that is with the beeper.

In normal operation, the beeper will only produce a single note of definite pitch and duration. Using BASIC programming and a FOR ...NEXT loop, you can get a varying succession of notes, but you can't get a smooth slide in pitch — the switch in and out of BASIC breaks the continuity. However, some simple machine code programming makes this possible.

The Spectrum does its BEEPing in a very simple way. The internal speaker is connected to one of the output ports of the Z80 processor (see p.118 of the manual). When the speaker bit (D4) is set, it activates the circuit and a click is produced at the speaker. By arranging that D4 switches on and off some hundreds of times a second, the ear interprets the clicks as a sound of definite pitch.

Clearly, with this system there can be no way, without extra hardware, of modifying the waveform and so changing the characteristics or volume of sound. However, there is one thing we can play with and that is pitch; we can (and do, whenever we set up new values for BEEP) alter the rate of clicks and so change the frequency of the note.

The way in which this program controls the rate of clicks is by setting up a count (about 100 is usually the right range) and outputting a click at the end of the count. Even a count of 100 cycles will occupy less than 10 microseconds, so the succession of clicks will produce a note well within the audible range.

If we arrange to vary the number in the count, increasing it or decreasing it regularly, we get a note that changes pitch apparently continuously, like a penny whistle.

Here is the machine code listing to do this:

Penny Whistle — up or down

```
F000 F3          DI
F001 11 10 00    LD    DE,0010
F004 26 0A       LD    H,0A
F006 3A 48 5C    LD    A,(5C48)
F009 1F          RRA
F00A 1F          RRA
F00B 1F          RRA
F00C 0E FE       LD    C,FE         OUTPUT PORT 254
F00E EE 10       XOR   10
F010 ED 79       OUT   (C),A
F012 43          LD    B,E
F013 10 FE       DJNZ  F013
F015 25          DEC   H
F016 20 F4       JR     NZ,F00C
F018 1C          INC   E
F019 15          DEC   D
F01A 20 E8       JR     NZ,F004
F01C FB          EI
F01D C9          RET
```

There are a couple of interesting points in the listing. In the first place, output port 254 sets the border colour, as well as driving the speaker (see p.160 of the manual). So, in order to preserve this colour, we collect it from the system variable BORDCR, at 5C48h, in line F006h, and then push the bits into the positions we require in the next three instructions. The XOR instruction at F00Dh switches the speaker bit on and off, as described in Chapter 6.

The DI at the start of the routine and the EI at the end are there to prevent the routine being interrupted by the keyboard scan. If this is allowed to occur, the interrupts superimpose their own 50 Hz hum on the note you are producing, spoiling the quality of the sound.

The H, DE and B registers are concerned with controlling the pitch of the note, the span of the slide and the total duration. E governs the pitch —it is the source register from which B is repeatedly loaded, to be used in a DJNZ operation to control the interval between clicks.

By incrementing E, a note will swoop down; decrementing E will make a note slide up.

H controls the number of cycles at a particular frequency, before the next increment or decrement. As a result of this function, H also controls the overall duration of the program.

D governs the number of intervals used; ie the span of the slide.

All the values can be altered experimentally and will considerably affect the type of sound produced, as might be expected. There is no fixed 'best fit', although the numbers given make a stab at an average.

By POKEing F018h (61464d) alternately with 1Ch (28d) for 'INC E' and 1Dh (29d) for 'DEC E', you can get an up-and-down swoop, something like a wolfwhistle, or a police siren.

There is a second sound effect which relies on changing frequency, which can therefore be produced by simple BEEPing techniques. This routine outputs two different notes at once. (I had originally hoped, when the program was planned, that the result would play a chord, but it doesn't work quite like that. Presumably, to sound a chord, you have to superimpose two separate, complete waveforms, rather than two sets of on/off signals at different frequencies.)

However, the program produces some interesting beat effects, ranging from a sort of rasping twitter to quite a bell-like clang.

Double Note

```
F000 F3          DI
F001 3A 48 5C    LD    A,(5C48)
F004 1F          RRA
F005 1F          RRA
F006 1F          RRA
F007 06 00       LD    B,00
F009 0E FE       LD    C,FE
F00B 25          DEC   H         COUNTER, LOOP 1
F00C 20 06       JR     NZ,F014
F00E EE 10       XOR   10
F010 ED 79       OUT   (C),A
F012 26 F0       LD    H,F0      SET COUNTER
F014 2D          DEC   L         COUNTER, LOOP 2
```

```
F015 20 F4        JR     NZ,F00B
F017 EE 10        XOR    10
F019 ED 79        OUT    (C),A
F01B 2E ED        LD     L,ED        SET COUNTER
F01D 10 EC        DJNZ   F00B
F01F FB           EI
F020 C9           RET
```

The program uses the same system to generate the sound as before, but this time there are two counters — one for note 1 and the other for note 2. The routine counts down on each of them alternately, and each time one of them reaches zero, it outputs to the speaker, after which the count is initialised again.

The number loaded into the B register, at F006h, controls the number of times the entire program cycles through before stopping, ie the duration of the note. Since only the B register is used, the biggest number it can deal with is 256d, so that the duration is limited. The actual length of the note also depends on the pitch — it will be longer for a deep note than it will be for a high note.

The BASIC program given below runs through a representative selection of note pairs. They vary in effect quite a lot, but the best seem to be when one note is nearly the same as the other, or nearly the same as one of its harmonics.

You could use this as part of an interrupt program, but the effect is somewhat spoiled by the fact that it must be produced in staccato bursts if your main program is to have a chance to run as well.

Run Through Double Notes

```
 100 FOR i=100 TO 250 STEP 50: FOR j=1 T
O 255
 110 POKE 61459,i: POKE 61468,j: RANDOMI
ZE USR 61440
 120 PRINT AT 10,10;i;TAB 15;j
 130 NEXT j: CLS : NEXT i
```

CHAPTER 14
Following a Machine Code Program — Hex/Dec

So far, we have mostly been considering routines which will end up as subroutines in larger-scale programs. But it can be interesting to work through a complete program in machine code and to recognise how it is put together and made accessible to the user.

I have tried to reconstruct in this chapter the thinking that went into making a program to convert decimal into hex and hex into decimal. I store this along with my assembler, so as to be able to convert addresses as required.

The program uses the Spectrum calculator to work out the hex or decimal digits. It's a moot point whether it is better to use the calculator to do the simple arithmetic required, or whether this would be better written into the program. Most simple calculations can be done using the 'ADD', 'SUB' or 'SHIFT' instructions to add, subtract, multiply or divide. For instance, 'times 10' is achieved like this:

```
Number in HL
ADD HL,HL   29    × 2
PUSH HL     E5    Store
ADD HL,HL   29    × 4
ADD HL,HL   29    × 8
POP BC      C1    (× 2 in BC)
ADD HL,BC   09    × 10
```

To do the same thing using the calculator requires the following:

```
Number in BC
CALL STACK_BC   CD 2B 2D   Number on Calc. stack
RST 28          EF         use Calc.
                A4         stack constant, '10'
                04         multiply
                38         end Calc.
```

The number is now on the top of the calculator stack, ready to be printed, using 'CALL PRINT_FP (CD E3 2D), the routine which prints out decimal numbers in full, including decimal points or 'E' notation as appropriate.

The calculator routines look a little obscure, because they use the Spectrum shorthand. Once the 'RST 28' instruction is reached in a program, the program no longer interprets the subsequent bytes as normal Z80 instructions, but as cues to call specific ROM routines, which do arithmetical or other tasks.

'A4' stacks the number 10d on the calculator stack, above the previous entries: '04' multiplies the two top entries on the stack together and leaves the answer in place of them: '38' signals the end of the calculation and a return to normal programming. A good machine code primer will give a complete list of these codes or 'literals'.

The 'Hex/Dec' program uses the calculator to work out the values of the numbers input, in either of the formats.

Looking at the program broadly, you can see that there will have to be two main subroutines, one to change hex into dec, and the other to change dec into hex. There will also have to be a master routine, which will switch to the required subroutine on request.

This master routine does not require any calculating — it is just a selection routine, with an input. If it gets 'H', it goes one way; if it gets 'D', it goes the other.

Let's see what that would look like:

Hex/Dec Selection

```
F000 FD CB 01 AE RES  5, (IY+01)
F004 FD CB 01 6E BIT  5, (IY+01)
F008 28 FA       JR    Z,F004
F00A 3A 08 5C    LD   A,(5C08)
F00D FE 48       CP   48
F00F 28 06       JR    Z,F017
F011 FE 44       CP   44
F013 28 53       JR    Z,F068
F015 18 E9       JR    F000
```

We have the same 'Wait for a key' listing which was described in Chapter 6, under the Typewriter routine. When the key code is in the A register, it is tested twice, once for 'H' (48h) and once for 'D' (44h). Either of these values gives a jump to a different address. Anything else goes back to the start.

However, left to itself, this input routine will be quite uncommunicative. It will just show a blank screen. We need some kind of message to be printed up, as a cue for action. So we add the following coding at the beginning:

Hex/Dec Selection with Cue Message

```
F000 3E 02          LD    A,02
F002 CD 01 16       CALL  1601

F005 11 00 F1       LD    DE,F100
F008 01 1E 00       LD    BC,001E
F00B CD 3C 20       CALL  203C
F00E FD CB 01 AE RES   5,  (IY+01)
F012 FD CB 01 6E BIT   5,  (IY+01)
F016 28 FA          JR     Z,F012
F018 3A 08 5C       LD    A,(5C08)
F01B FE 48          CP    48
F01D 28 06          JR     Z,F025
F01F FE 44          CP    44
F021 28 53          JR     Z,F076
F023 18 E9          JR     F00E
```

The first two instructions set the printing for the upper screen; then we point to a message in DE of length BC and call PR_STRING (203Ch).

The coding for the message has to be entered at the F100h address. It is 30 bytes long (1Eh) and looks like this:

Hex/Dec Message — 1

```
DEFB:-
F100 EE 22 12 01 48 12 00 22
F108 EB 48 45 58 0D EE 22 12
F110 01 44 12 00 22 EB 44 45
F118 43 49 4D 41 4C 0D
```

Printing up the 'printable' characters of this message gives this result:

Hex/Dec Message — 2

```
DEFB:-
F100   .   "   .   .   H   .   .   "
F108   .   H   E   X   .   .   "   .
F110   .   D   .   .   "   .   D   E
F118 C   I   M   A   L   .
```

Part of the text seems legible, but a lot of it seems to be missing. The 'missing' bytes contain Spectrum character codes for items other than letters. 'EEh' is the code for the word 'INPUT', as you will see if you look at the manual (p.183). '12h' codes for 'FLASH' and the following '01h' is interpreted by the PR_STRING routine as 'FLASH 1'. The '12 00', two characters later, gives 'FLASH 0'. 'EB' codes for 'FOR', complete with space after it.

The entire coding corresponds to the BASIC line

```
  10 PRINT "INPUT """; FLASH 1;"H"; FLAS
H 0;""" FOR HEX"'"INPUT """; FLASH 1;"D"
; FLASH 0;""" FOR DECIMAL"
```

It appears on the screen as,

INPUT "H" FOR HEX
INPUT "D" FOR DECIMAL

with the 'H' and the 'D' flashing.

You can try out this whole section of the program if you put RETs at F025h and F076h. But, remember, the routine is looking for *capital* 'D' and 'H'. We shall have to write in something to make sure that the CAPS LOCK is on.

From hex into dec

It's now time to consider the two subroutines. 'Hex into Dec' is probably the simpler, so let's look at that first.

Since the top address we are going to need to deal with is limited to FFFFh, the program will never need to use more than four hex digits. We need to organise input in a loop with '× 4' loop control. Each pass of the loop will multiply the existing total by 16d, and then add to it the value of the hex digit just input. We shall arrange to make the initial total 0 so that, after the four passes, the value of our total will be that of the four hex digits and we can print it in decimal form using PRINT_FP.

The first step is to get the value of the digit input. We can use the 'Wait for a key' routine again and get the key code into A. Next we want to make sure that what we have is a valid hex digit. Luckily, there is a little ROM subroutine at 2D1Bh, which will check to see if the input is a numeral between '0' and '9'. If the key code fails this, we have to check whether it lies between 'A' and 'F'. Only if the key code passes all these tests will the program continue. If it *is* OK, we had better print the digit, too.

Hex/Dec — Input Hex Digit

```
E000 FD CB 01 AE RES   5, (IY+01)
E004 FD CB 01 6E BIT   5, (IY+01)
E008 28 FA       JR      Z,E004
E00A 3A 08 5C    LD    A,(5C08)
E00D CD 1B 2D    CALL  2D1B
E010 30 08       JR     NC,E01A
E012 FE 41       CP    41           'A'
E014 38 EA       JR      C,E000
E016 FE 47       CP    47           'F'
E018 30 E6       JR     NC,E000
E01A F5          PUSH  AF
E01B D7          RST   10           PRINT
E01C F1          POP   AF
E01D C9          RET
```

Now to do the multiplying and adding. We need to have the value '16' ready somewhere in the calculator, to do our multiplying. We also need to have a zero on the calculator stack at the start of operations. Both of these preparations had better be made before we start inputting digits.

The best place for the '16' is in the calculator's memory. It can stay there as long as wanted and be called out on to the stack, by a single literal, each time we need to use it. You get it to the memory by stacking it and then using the literal 'C0'. So our opening gambit is:

Hex/Dec — Value 16d to Calculator Memory

```
E000 3E 10          LD    A,10
E002 CD 28 2D       CALL  2D28
E005 EF             RST   28
E006 C0       stk mem 0
E007 38       end calc.
E008 AF             XOR   A
E009 CD 28 2D       CALL  2D28
```

After INPUT, we have a value in A which is either '0' to '9' or 'A' to 'F'. However, the value of key code 'A' is not one more than key code '9' — it is eight more. We have to do a little more adjusting, before we can be sure that we have got the value right. So, continuing with our complete listing, to date, this is:

Hex/Dec — Hex Input, Opening Section

```
E000 3E 10          LD    A,10
```

```
E002 CD 28 2D       CALL  2D28
E005 EF             RST   28
E006 C0       stk mem 0
E007 38       end calc.
E008 AF             XOR   A
E009 CD 28 2D       CALL  2D28

E00C FD CB 01 AE    RES   5, (IY+01)
E010 FD CB 01 6E    BIT   5, (IY+01)
E014 28 FA          JR      Z,E010
E016 3A 08 5C       LD    A,(5C08)
E019 CD 1B 2D       CALL  2D1B

E01C 30 08          JR     NC,E026
E01E FE 41          CP    41
E020 38 EA          JR      C,E00C
E022 FE 47          CP    47
E024 30 E6          JR     NC,E00C

E026 F5             PUSH  AF
E027 D7             RST   10
E028 F1             POP   AF

E029 FE 41          CP    41
E02B 38 02          JR      C,E02F
E02D D6 07          SUB   07
```

Now we had better PUSH our value in A, as we are going to do some arithmetic which will corrupt this register. The first thing is to multiply the existing calculator stack value by 16.

```
EF    RST 28
E0    get MEM,0 on stack (this is '16')
04    multiply
38    end Calc.
```

Now we can POP AF again and stack it.

```
F1          POP  AF
CD 26 2D    CALL "STK__DIGIT" +
```

The last call, to 2D26h, is a modified CALL to STK__DIGIT, which stacks the value of a valid ASCII numeral. Since our own offering may not be a numeral (it may be 'A' to 'F') but one we know is valid, we skip the checking procedure, between 2D22h and 2D25h, which might otherwise reject it.

Now back to the calculator again.

```
EF      RST 28
0F        add
38        end Calc.
```

This adds the original value on the stack (multiplied by 16) to the new value just input, and leaves the result as the top item on the stack.

If we arrange to do this four times, we have the value of a four-digit hex number on the stack, which can be printed in decimal with the PRINT_FP routine.

So, for the grand finale, which only needs a printed input cue to complete it:

Hex/Dec — Hex Input Complete

```
E000 3E 10            LD    A,10
E002 CD 28 2D         CALL  2D28          16D TO CALC. MEM 0
E005 EF               RST   28
E006 C0          stk mem 0
E007 38          end calc.
E008 AF               XOR   A
E009 CD 28 2D         CALL  2D28          0 TO CALC. STACK

E00C 06 04            LD    B,04          4 DIGIT COUNT
E00E C5               PUSH  BC

E00F FD CB 01 AE      RES   5, (IY+01)
E013 FD CB 01 6E      BIT   5, (IY+01)    WAIT FOR KEY
E017 28 FA            JR      Z,E013
E019 3A 08 5C         LD    A,(5C08)
E01C CD 1B 2D         CALL  2D1B          CHECK '0'-'9'?

E01F 30 08            JR     NC,E029
E021 FE 41            CP    41
E023 38 EA            JR      C,E00F      CHECK 'A'-'F'?
E025 FE 47            CP    47
E027 30 E6            JR     NC,E00F

E029 F5               PUSH  AF            PRINT HEX DIGIT
E02A D7               RST   10
E02B F1               POP   AF

E02C FE 41            CP    41
E02E 38 02            JR      C,E032      ADJUST VALUE IF 'A'-'F'
```

```
E030 D6 07          SUB   07
E032 F5             PUSH  AF

E033 EF             RST   28
E034 E0    get mem 0                 MULTIPLY STACK TOP
E035 04 •  multiply                    BY 16D
E036 38    end calc.
E037 F1             POP   AF
E038 CD 26 2D       CALL  2D26       STACK VALUE IN A
E03B EF             RST   28
E03C 0F    add                       ADD NEW VALUE TO
E03D 38    end calc.                   STACK TOP

E03E C1             POP   BC         COUNT
E03F 10 CD          DJNZ  E00E

E041 3E 06          LD    A,06       PRINT 'TAB 16' (=,)
E043 D7             RST   10
E044 CD E3 2D       CALL  2DE3       PRINT DECIMAL NUMBER
E047 C9             RET
```

From dec to hex

The second subroutine, to go from decimal to hex, follows much the same lines, except that we multiply the total by 10d, rather than 16d, on each pass. Also, we have no ready-made routine for printing out hex digits, so we shall have to write one ourselves.

Each time we extract a hex digit from the number we are working on, we shall produce a value in A which must lie between 0–15d (0–Fh).

Simply by adding 48d (30h), we shall get the codes for the decimal numerals. In the case of the values from 10d to 15d, we have to arrange to add a further 7 to bring it up to the codes for 'A' to 'F'. So the coding will look like this:

Dec/Hex — Print Hex Digit

```
E200 FE 0A          CP    0A
E202 38 02          JR       C,E206
E204 C6 07          ADD   A,07
E206 D7             RST   10
E209 C9             RET
```

We also need to work out how we are going to extract these hex digits from the value of the complete number entered. This turns out to be very easy. Suppose that our value is held in a register pair (it will need to be a pair, as the maximum value we shall be dealing with, FFFFh, needs more than one register to hold it). The value will be in the form 'xxxx', where each 'x' is a hex digit. So we just need a simple program, to extract each nibble in turn from the register pair and send it off to the printing subroutine which we have just written.

Assuming that the value is in BC, the following would do the job:

Dec/Hex — Print Hex Digits (1)

```
E100 78          LD    A,B
E101 E6 F0       AND   F0
E103 1F          RRA
E104 1F          RRA
E105 1F          RRA
E106 1F          RRA
E107 CD 00 E2    CALL  E200   PRINT ROUTINE
E10A 78          LD    A,B
E10B E6 0F       AND   0F
E10D CD 00 E2    CALL  E200   PRINT ROUTINE
E110 79          LD    A,C
E111 E6 F0       AND   F0
E113 1F          RRA
E114 1F          RRA
E115 1F          RRA
E116 1F          RRA
E117 CD 00 E2    CALL  E200   PRINT ROUTINE
E11A 79          LD    A,C
E11B E6 0F       AND   0F
E11D CD 00 E2    CALL  E200   PRINT ROUTINE
E120 C9          RET
```

The only possible drawback to this version is that it is not relocatable — it relies on a subroutine CALL, which has to be at a fixed address. We might be able to get rid of this, if we arranged a '× 4' loop and shifted the nibbles into A, rather than masking them with the AND.

Dec/Hex — Print Hex Digits (2)

```
E100 1E 04       LD    E,04
E102 16 04       LD    D,04
E104 AF          XOR   A
E105 CB 11       RL    C
E107 CB 10       RL    B
E109 17          RLA
E10A 15          DEC   D
E10B 20 F8       JR     NZ,E105
E10D FE 0A       CP    0A
E10F 38 02       JR      C,E113
```

```
E111 C6 07          ADD  A,07
E113 C6 30          ADD  A,30
E115 D7             RST  10
E116 1D             DEC  E
E117 20 E9          JR    NZ,E102
E119 C9             RET
```

As it turns out, the second version is shorter, as well as being relocatable, although it does use an extra register. On the whole, it seems the better one, so let's adopt it.

Now for the input and value extracting.

Most of the first part of the routine is virtually a carbon copy of the hex/dec one. You do not have to place 10h (16d) in the calculator memory: there is a constant 0Ah (10d) permanently on call among the other constants in the Spectrum system. Also, you no longer have to check the digits to see that they fall between 'A' and 'F' — they can only be ordinary numerals. So the routine, up to the print section, looks like this:

Dec/Hex — Input Decimal, part 1

```
E200 AF                 XOR  A
E201 CD 28 2D           CALL 2D28
E204 06 05              LD   B,05              MAX. NO. OF DIGITS
E206 C5                 PUSH BC
E207 FD CB 01 AE        RES  5, (IY+01)
E20B FD CB 01 6E        BIT  5, (IY+01)
E20F 28 FA              JR    Z,E20B
E211 3A 08 5C           LD   A,(5C08)
E214 CD 1B 2D           CALL 2D1B              CHECK '0'-'9'
E217 38 EE              JR    C,E207
E219 F5                 PUSH AF
E21A D7                 RST  10                PRINT DEC. DIGIT
E21B F1                 POP  AF
E21C F5                 PUSH AF
E21D EF                 RST  28
E21E A4         constant 10
E21F 04         multiply
E220 38         end calc.
E221 F1                 POP  AF
E222 CD 22 2D           CALL 2D22              STK_DIGIT
E225 EF                 RST  28
E226 0F         add
E227 38         end calc.
E228 C1                 POP  BC
```

```
E229  10 DB          DJNZ  E206
E22B  CD A2 2D       CALL  2DA2
E22E  C9             RET
```

The last CALL, to 2DA2h, is to the ROM FP__TO__BC routine. This puts the value of the floating point number at the top of the calculator stack into the BC register. From here, as we have found, it is a simple matter to print out the value in hex. Before the printout, we once again do a 'TAB 16;', by PRINTing CHR 06h.

Dec/Hex — Decimal Input, Complete

```
E200  AF             XOR   A
E201  CD 28 2D       CALL  2D28
E204  06 05          LD    B,05
E206  C5             PUSH  BC
E207  FD CB 01 AE    RES   5,  (IY+01)
E20B  FD CB 01 6E    BIT   5,  (IY+01)
E20F  28 FA          JR     Z,E20B
E211  3A 08 5C       LD    A,(5C08)
E214  FE 0D          CP    0D
E216  20 03          JR     NZ,E21B
E218  C1            .POP   BC
E219  18 17          JR     E232
E21B  CD 1B 2D       CALL  2D1B
E21E  38 E7          JR     C,E207
E220  F5             PUSH  AF
E221  D7             RST   10
E222  F1             POP   AF
E223  F5             PUSH  AF
E224  EF             RST   28
E225  A4        constant  10
E226  04        multiply
E227  38        end calc.
E228  F1             POP   AF
E229  CD 22 2D       CALL  2D22
E22C  EF             RST   28
E22D  0F        add
E22E  38        end calc.
E22F  C1             POP   BC
E230  10 D4          DJNZ  E206
E232  3E 06          LD    A,06
E234  D7             RST   10
E235  CD A2 2D       CALL  2DA2
E238  1E 04          LD    E,04
```

```
E23A  16 04        LD    D,04
E23C  AF           XOR   A
E23D  CB 11        RL    C
E23F  CB 10        RL    B
E241  17           RLA
E242  15           DEC   D
E243  20 F8        JR     NZ,E23D
E245  FE 0A        CP    0A
E247  38 02        JR     C,E24B
E249  C6 07        ADD   A,07
E24B  C6 30        ADD   A,30
E24D  D7           RST   10
E24E  1D           DEC   E
E24F  20 E9        JR     NZ,E23A
E251  C9           RET
```

This has assembled all the main components of the complete program. We still have to write labels for the two subroutines and initialise with a CAPS LOCK.

Looked at schematically, the program when grouped together has this shape:

Initialise	F000–F011
Set CAPS	
Open screen channel	
Message	
Menu	F012–F028
Wait for key	
Choose 'H'	
Choose 'D'	
Hex/Dec message	F029-F031
Set up calculator	F032–F03D
Hex value input & calculate	F03E–F072
End routine	F073–F07A
Print 'Tab 16' and number	
Jump to 'finalise'	
Dec/Hex message	F07B–F083
Set up calculator	F084–F087
Dec value input & calculate	F088–F0B5
Calculate & print hex	F0B6–F0D4
Finalise	F0D5–F0E3
Wait for key	
Reset CAPS	
Return	

Here it is, printed in full.

Hex/Dec

```
F000 FD CB 30 DE SET   3,  (IY+30)
F004 3E 02       LD    A,02
F006 CD 01 16    CALL  1601
F009 11 00 F1    LD    DE,F100
F00C 01 1E 00    LD    BC,001E
F00F CD 3C 20    CALL  203C
F012 FD CB 01 AE RES   5,  (IY+01)
F016 FD CB 01 6E BIT   5,  (IY+01)
F01A 28 FA       JR      Z,F016
F01C 3A 08 5C    LD    A,(5C08)
F01F FE 48       CP    48
F021 28 06       JR      Z,F029
F023 FE 44       CP    44
F025 28 53       JR      Z.F07A
F027 18 E9       JR     F012

F029 11 40 F1    LD    DE,F140
F02C 01 26 00    LD    BC,0026
F02F CD 3C 20    CALL  203C

F032 3E 10       LD    A,10
F034 CD 2B 2D    CALL  2D2B
F037 EF          RST   28
F038 C0       stk mem 0
F039 38       end calc.
F03A AF          XOR   A
F03B CD 2B 2D    CALL  2D2B

F03E 06 04       LD    B,04
F040 C5          PUSH  BC
F041 FD CB 01 AE RES   5,  (IY+01)
F045 FD CB 01 6E BIT   5,  (IY+01)
F049 28 FA       JR      Z,F045
F04B 3A 08 5C    LD    A,(5C08)
F04E CD 1B 2D    CALL  2D1B
F051 30 08       JR     NC,F05B
F053 FE 41       CP    41
F055 38 EA       JR      C,F041
F057 FE 47       CP    47
F059 30 E6       JR     NC,F041
F05B F5          PUSH  AF
F05C D7          RST   10
F05D F1          POP   AF
```

```
FØ5E FE 41           CP    41
FØ6Ø 38 Ø2           JR      C,FØ64
FØ62 D6 Ø7           SUB   Ø7
FØ64 F5              PUSH AF
FØ65 EF              RST   28
FØ66 EØ  · get mem Ø
FØ67 Ø4    multiply
FØ68 38    end calc.
FØ69 F1              POP   AF
FØ6A CD 26 2D        CALL 2D26
FØ6D EF              RST   28
FØ6E ØF    add
FØ6F 38    end calc.
FØ7Ø C1              POP   BC
FØ71 1Ø CD           DJNZ FØ4Ø

FØ73 3E Ø6           LD    A,Ø6
FØ75 D7              RST   1Ø
FØ76 CD E3 2D        CALL 2DE3
FØ79 18 5A           JR      FØD5
FØ7B 11 1E F1        LD    DE,F11E
FØ7E Ø1 22 ØØ        LD    BC,ØØ22
FØ81 CD 3C 2Ø        CALL 2Ø3C

FØ84 AF              XOR   A
FØ85 CD 28 2D        CALL 2D28

FØ88 Ø6 Ø5           LD    B,Ø5
FØ8A C5              PUSH BC
FØ8B FD CB Ø1 AE RES   5,  (IY+Ø1)
FØ8F FD CB Ø1 6E BIT   5,  (IY+Ø1)
FØ93 28 FA           JR      Z,FØ8F
FØ95 3A Ø8 5C        LD    A,(5CØ8)
FØ98 FE ØD           CP    ØD
FØ9A 2Ø Ø3           JR      NZ,FØ9F
FØ9C C1              POP   BC
FØ9D 18 17           JR      FØB6
FØ9F CD 1B 2D        CALL 2D1B
FØA2 38 E7           JR      C,FØ8B
FØA4 F5              PUSH AF
FØA5 D7              RST   1Ø
FØA6 F1              POP   AF
FØA7 F5              PUSH AF
FØA8 EF              RST   28
FØA9 A4    constant 1Ø
```

```
F0AA 04          multiply
F0AB 38          end calc.
F0AC F1                  POP  AF
F0AD CD 22 2D            CALL 2D22
F0B0 EF                  RST  28
F0B1 0F          add
F0B2 38          end calc.
F0B3 C1                  POP  BC
F0B4 10 D4               DJNZ F08A
F0B6 3E 06               LD   A,06
F0B8 D7                  RST  10
F0B9 CD A2 2D            CALL 2DA2
F0BC 1E 04               LD   E,04
F0BE 16 04               LD   D,04
F0C0 AF                  XOR  A
F0C1 CB 11               RL   C
F0C3 CB 10               RL   B
F0C5 17                  RLA
F0C6 15                  DEC  D
F0C7 20 F8               JR    NZ,F0C1
F0C9 FE 0A               CP   0A
F0CB 38 02               JR     C,F0CF
F0CD C6 07               ADD  A,07
F0CF C6 30               ADD  A,30
F0D1 D7                  RST  10
F0D2 1D                  DEC  E
F0D3 20 E9               JR    NZ,F0BE

F0D5 FD CB 01 AE  RES  5,  (IY+01)
F0D9 FD CB 01 6E  BIT  5,  (IY+01)
F0DD 28 FA        JR     Z,F0D9
F0DF FD CB 30 9E  RES  3,  (IY+30)
F0E3 C9           RET
```

The data for the messages are arranged as follows:

```
DEFB:-
F100 EE 22 12 01 48 12 00 22
F108 EB 48 45 58 0D EE 22 12
F110 01 44 12 00 22 EB 44 45
F118 43 49 4D 41 4C 0D 14 01
F120 44 45 43 49 4D 41 4C 14
F128 00 EE 55 50 CC 35 20 44
F130 49 47 49 54 53 0D 2B 20
F138 22 45 4E 54 45 52 22 0D
```

```
F140  14  01  48  45  58  14  00  EE
F148  34  20  44  49  47  49  54  53
F150  0D  28  57  49  54  48  20  4C
F158  45  41  44  49  4E  47  20  5A
F160  45  52  4F  53  29  0D
```

yielding the following characters:

```
F100  .  "  .  .  H  .  .  "
F108  .  H  E  X  .  .  "  .
F110  .  D  .  .  "  .  D  E
F118  C  I  M  A  L  .  .  .
F120  D  E  C  I  M  A  L  .
F128  .  .  U  P  .  5     D
F130  I  G  I  T  S  .  +
F138  "  E  N  T  E  R  "  .
F140  .  .  H  E  X  .  .  .
F148  4     D  I  G  I  T  S
F150  .  (  W  I  T  H     L
F158  E  A  D  I  N  G     Z
F160  E  R  O  S  )  .
```

When printed out, the messages should look like this:

```
INPUT "H" FOR HEX
INPUT "D" FOR DECIMAL
```

```
HEX INPUT 4 DIGITS
(WITH LEADING ZEROS)
```

```
DECIMAL INPUT UP TO 5 DIGITS
+ "ENTER"
```

The whole program can be used by a machine code CALL to F000h. When used from a BASIC program, you would need 'RANDOMIZE USR 61440'.

APPENDIX A
Machine Code Routines

PaintCODE

This machine code program will INK in any line drawn figure on the Spectrum, so enabling you to produce solid coloured shapes which otherwise might be difficult.

Unfortunately, like most good things in life, it is not perfect. This is a result of the way in which the routine tackles this problem.

The routine paints the figure by looking at the screen a line at a time and joining together any pairs of dots it finds. It does this by setting all the bits in between the pairs of dots. Unfortunately, it sometimes gets in a muddle when it comes across a line with an odd number of dots, when it has no way of telling which dots go with each other: it produces lines where there should be blanks and vice versa.

To eliminate this would require a much extended program which looked at the lines on either side, as well as the one being changed. Life is too short, considering the use the program gets.

PaintCODE

```
F000 21 00 40    LD    HL,4000
F003 1E C0       LD    E,C0
F005 0E 20       LD    C,20
F007 06 08       LD    B,08
F009 7E          LD    A,(HL)
F00A 07          RLCA
F00B 38 11       JR     C,F01E
F00D 10 FB       DJNZ  F00A
F00F 77          LD    (HL),A
F010 23          INC   HL
F011 0D          DEC   C
F012 20 F3       JR     NZ,F007
F014 1D          DEC   E
F015 20 EE       JR     NZ,F005
F017 C9          RET
F018 06 08       LD    B,08
F01A 7E          LD    A,(HL)
```

```
F01B 07         RLCA
F01C 30 08      JR     NC,F026
F01E 10 FB      DJNZ F01B
F020 23         INC   HL
F021 0D         DEC   C
F022 28 F0      JR     Z,F014
F024 18 F2      JR     F018
F026 C5         PUSH BC
F027 E5         PUSH HL
F028 F5         PUSH AF
F029 18 06      JR     F031
F02B 06 08      LD    B,08
F02D 7E         LD    A,(HL)
F02E 07         RLCA
F02F 38 08      JR     C,F039
F031 10 FB      DJNZ F02E
F033 23         INC   HL
F034 0D         DEC   C
F035 20 F4      JR     NZ,F02B
F037 18 16      JR     F04F
F039 F1         POP   AF
F03A E1         POP   HL
F03B C1         POP   BC
F03C 18 04      JR     F042
F03E 06 08      LD    B,08
F040 7E         LD    A,(HL)
F041 07         RLCA
F042 CB C7      SET   0,A
F044 38 11      JR     C,F057
F046 10 F9      DJNZ F041
F048 77         LD    (HL),A
F049 23         INC   HL
F04A 0D         DEC   C
F04B 20 F1      JR     NZ,F03E
F04D 18 03      JR     F052
F04F F1         POP   AF
F050 F1         POP   AF
F051 F1         POP   AF
F052 18 C0      JR     F014
F054 07         RLCA
F055 38 04      JR     C,F05B
F057 10 FB      DJNZ F054
F059 18 B4      JR     F00F
F05B F5         PUSH AF
```

```
F05C C5          PUSH BC
F05D 18 01       JR    F060
F05F 07          RLCA
F060 10 FD       DJNZ F05F
F062 77          LD    (HL),A
F063 C1          POP  BC
F064 F1          POP  AF
F065 18 B7       JR    F01E
```

Mapper

In order to draw the shapes which can be filled in with the PaintCODE routine, you might use a program like this one:

Mapper

```
   5 POKE 23660,5: LET a=0
  10 INPUT "x";x;"y";y
  20 PLOT INVERSE a;x,y
  30 PRINT #1;AT 0,12;"3=</ 4=<\ 9=>/ 0=
>\"
  40 PAUSE 0
  50 LET y$=INKEY$
  60 LET x=x-(y$="3")-(y$="4")-(y$="5")+
(y$="8")+(y$="9")+(y$="0")
  70 LET y=y-(y$="3")+(y$="4")-(y$="6")+
(y$="7")+(y$="9")-(y$="0")
  80 IF y$="1" THEN RANDOMIZE USR (5+PEE
K 23635+256*PEEK 23636)
  90 LET x=x-(x>255)+(x<0): LET y=y-(y>1
75)+(y<0)
 100 GO TO 20
```

It is very similar to the Draw a Sprite program in Chapter 8, but the programming is more compact and it will draw over the whole screen.

PaintCODE has to be put into a line 1 REM statement, as described in Chapter 1. Once again, it is accessed indirectly, using the system variable PROG, so as to get the right address whether or not Interface 1 is in place (see Chapters 1 and 6).

You can also use Mapper to touch out those unwanted lines where PaintCODE has got its sums wrong.

Find z$

You often need to find the address of a BASIC program string in the course of a machine code program. There are routines to discover the address of the actual string, but they have to be set up for each individual case, and there is no really suitable ROM routine.

There is a lot to be said for making a rule to copy the string under consideration into another string, which can be consistently addressed by the machine code. A convenient string to choose is 'z$'. If you put the chosen string, or element of a string array, into z$ immediately before calling the machine code routine with 'USR xxxxx', z$ will always be the last string in the variables area, before E_LINE. You can then be sure of finding its address by a simple search routine.

Unfortunately, the code which signals the start of a simple string in the variables is the same as the code for the capital version of the letter which names the string — in this case, capital 'Z'. Because there is a chance that this letter might feature in the string, we have to check that there is no mistake. This can be done by checking the next character but one, which will almost certainly not be a printable character if the letter signals a string — unless the string is extremely long (see the diagram on p.168 of the manual).

If, for some reason, the search fails and 'Z' cannot be found, the program will drop into BASIC with an error message.

Find z$

```
F000 3E 5A          LD    A,5A
F002 A7             AND   A
F003 2A 59 5C       LD    HL,(5C59)
F006 ED 4B 4B 5C    LD    BC,(5C4B)
F00A E5             PUSH  HL
F00B ED 42          SBC   HL,BC
F00D 44             LD    B,H
F00E 4D             LD    C,L
F00F 0C             INC   C
F010 E1             POP   HL
F011 ED B9          CPDR
F013 28 02          JR       Z,F017
F015 CF             RST   08
F016 01             DEFB  01           ERROR REPORT 2
F017 23             INC   HL
F018 23             INC   HL
F019 23             INC   HL
F01A 3E 1F          LD    A,1F
F01C BE             CP    (HL)
F01D 2B             DEC   HL
F01E 2B             DEC   HL
F01F 2B             DEC   HL
```

```
F020 3E 5A        LD    A,5A
F022 38 ED        JR      C,F011
F024 23           INC   HL
F025 23           INC   HL
F026 4E           LD    C,(HL)
F027 23           INC   HL
F028 46           LD    B,(HL)
F029 23           INC   HL
F02A C9           RET
```

The address of the first character of z$ is returned in HL and the length of the string in BC.

Pip routine

One of the attractive touches about the Spectrum is the way in which it makes a little click when a key is depressed, like a mechanical typewriter. This is a great help to people like myself, who are not touch typists and cannot watch the screen when they are using the keyboard. It verifies that a key has actually been struck.

The routine below is a straight copy of the method used in the ROM to produce the click, so that you can have the same advantage when inputting machine code routines.

All the prime registers and the IX register are affected by the routine, hence the mass of PUSHes and POPs which surround the three instructions.

This routine can be set up as a subroutine in your machine code programs, and CALLed after every input from the keyboard.

Pip routine

```
F000 DD E5        PUSH  IX
F002 E5           PUSH  HL
F003 D5           PUSH  DE
F004 C5           PUSH  BC
F005 11 00 00     LD    DE,0000
F008 21 CB 00     LD    HL,00CB
F00B CD B5 03     CALL  03B5        ROM BEEPER ROUTINE
F00E C1           POP   BC
F00F D1           POP   DE
F010 E1           POP   HL
F011 DD E1        POP   IX
F013 C9           RET
```

Alternatively, if you are using a BASIC program and can spare a couple of UDG characters, you could try the following:

Pip BASIC

```
  10 DATA 17,0,0,33,203,0,205,181,3,201
  20 FOR j=0 TO 9: READ n: POKE USR "A"+
j,n: NEXT j
  99 REM DEMONSTRATION
 100 PAUSE 0: RANDOMIZE USR USR "A": GO
TO 100
```

This allows you to make a click when you are taking an INKEY$ value after a 'PAUSE 0', in place of the normal 'INPUT...'.

I rather like the 'USR USR'. Of course, USR 'A' (or any other UDG letter) is simply an address in the upper RAM. And you are not limited to POKEing it with a sequence of eight positions to make a graphic character.

Since we are dealing with a BASIC program, we don't have to bother about saving and restoring all the registers.

APPENDIX B
Some ROM Subroutines

0010
PRINT_A_1

The address called by 'RST 10' (the opcode D7), which leads to the main printing routine. This must be the most used routine in the Spectrum's book. It will print to the screen in the current print position (upper or lower screen), or send to the printer, according to the channel set, any printable character held in A. It will print the expanded labels corresponding to the appropriate character codes. It will evaluate the control characters in the first 20 positions of the character set. In fact, it works like an Aladdin's lamp for the Spectrum display.

0028
FP_CALC

Another entry point to extended routines, this one is called by 'RST 28' (opcode EF). 'RST 28' accesses the calculator, which is a world of its own, with its own set of rules.

0038
MASK_INT

The maskable interrupt routine. Normally activated every 20 microseconds to update the Spectrum clock and scan the keyboard.

03B5
BEEPER

HL must hold the pitch and DE the duration. Also used to produce the keyboard click.

04C2
SA_BYTES

This is the complete SAVE routine, used to save all bytes. Also used for the header.

0556 LD_BYTES	LOAD routine. IX holds the start address and DE the number of bytes to be LOADed. The carry flag must be set for LOADing: if it is reset, the routine will VERIFY.
0970 SA_CONTRL	SAVE routine. IX holds the start address and DE the number of bytes to be SAVEd. This routine contains the whole normal SAVE routine, including the 'Wait for a key' pause. Entry at 0984h skips the wait for input.
0D6B CLS	Channel 'S' (No. 2 — upper screen) must be opened before and after CALLing.
0DD9 CL_SET	Calculates and sets DF_CC when S_POSN values are held in BC.
0E44 CL_LINE	This routine will clear a specified number of lines starting from the bottom (line 24). The number of lines to be cleared must be specified in B. '06 18' would clear the whole screen.
0EAC COPY	The printer channel (No. 3) must be opened first (see below).
1601 CHAN_OPEN	Open channel routine. Used in the form, 'LD A,x CALL 1601': x = 1 for lower screen, x = 2 for upper screen, x = 3 for printer.
16C5 SET_STK	This routine clears the calculator stack. Used in calculator operations.
203C PR_STRING	Prints string ($) with start address in DE and length in BC. The routine uses 'RST 10', so control characters, etc., will also be activated.
22AA PIXEL_AD	Takes POINT coordinate in BC and delivers the display file byte position in HL, also the point position within the byte in A.

2D1B NUMERIC	Verifies that A holds an ASCII digit, between 0 and 9. Carry flag set, if valid. Used in STK_NUM routine.
2D22 STK_DIGIT	Valid ASCII digit in A passed to calculator stack as floating point number.
2D28 STACK_A	Value in A passed to calculator stack.
2D2B STACK_BC	Value in BC passed to calculator stack.
2DA2 FP_TO_BC	This is an 'unstacking' routine. Passes the value of the floating point integer at the top of the stack to the BC register.
2DD5 FP_TO_A	Another unstacking routine. Passes the value of the floating point integer at the top of the calculator stack to the A register.
2DE3 PRINT_FP	The floating point number on the top of the calculator stack is printed in decimal (including decimal point) or 'E' notation, as appropriate.

These routines represent only a small number of the total routines stored in the ROM and used in the implementation of the Spectrum BASIC programming. Fuller guides to the Spectrum ROM will give further information on this important subject.

Index

This index was prepared on a ZX Spectrum and printed on a ZX printer. For technical reasons, it has been reset here, but a sample of the original copy is given below. The program uses many of the routines and enhanced characters described in this book. For those interested, further particulars can be obtained from the author, c/o Sunshine Books.

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John Durst is a former film director who decided to confront animation problems on his Spectrum. He is a regular contributor to Popular Computing Weekly.

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